Energy and Emissions Impacts of Atlanta's Reversible Express Toll Lanes and High-Occupancy Toll Lanes

August 2024

A Research Report from the National Center for Sustainable Transportation

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This report summarizes the impact on corridor-level energy use and emissions associated with the 2018 opening of the I-75 Northwest Corridor (NWC) and I-85 Express Lanes in Atlanta, GA. The research team tracked changes in vehicle throughput on the managed lane corridors (extracted from GDOT's Georgia NaviGAtor machine vision system after comprehensive QA/QC) and performed a difference-in-difference analysis to exclude regional changes, pairing test sites vs. control sites not influenced by the openings. The results show a large increase in overall peak-period vehicle throughput on the NWC, especially on I-575, due to the congestion decrease (20 mph speed increases at some locations). The increase in corridor-level energy use and emissions was smaller than vehicle throughput, but still significant. Predicted downwind maximum CO concentrations only increased from 1.81 ppm to 1.93 ppm (which remains extremely low). The increase in morning peak activity on the corridor likely resulted from diversion of some traffic into the peak from the shoulder periods, diversion of some traffic from other nearby freeway corridors, and diversion of local road traffic into the corridor. Unfortunately, without overall control volume totals and/or pre-and-post travel behavior surveys for the alternative commute routes, it is not possible to quantify the likely reductions in traffic flow and emissions that occurred along the other corridors that likely resulted from morning commute shifts. Hence, the team cannot draw reliable conclusions related to net regional or sub-regional impacts associated with the new managed lane corridors. The impact observed on the I-85 corridor was much smaller than on the NWC, especially at Indian Trail/Lilburn Road (far from the Express Lane Extension). After the Express Lanes opened, energy use and emission rates at Old Peachtree Road increased slightly (as uncongested vehicle speeds increased), but this increase may be short-lived as traffic on the corridor changes over time.</td></tr>
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Disclaimer

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Energy and Emissions Impacts of Atlanta's Reversible Express Toll Lanes and High-Occupancy Toll Lanes

A National Center for Sustainable Transportation Research Report

August 2024

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EXECUTIVE SUMMARY

As with any major civil engineering project, it is important to assess the impact of newly-constructed managed lane facilities on energy use and the environment. However, for facilities that reduce congestion and may significantly influence travel behavior given the reduction in travel time, it is often challenging to disentangle the facility impact from other factors such as regional growth and sub-regional shifts in vehicle activity, changes in fleet composition and improvement of vehicle and engine technologies over time, etc. The study reported herein compares corridor-level traffic conditions, along with energy use and emissions, after the opening of two new Express Lane facilities in Atlanta, Georgia, to a contrafactual scenario in which the facilities were not constructed.

For the I-75/I-575 Northwest Corridor Express Lanes and I-85 HOT Lanes extensions that opened in 2019 in the Atlanta Metro area, this research quantifies the net changes in vehicle throughput, energy use, and emission of criteria pollutants (CO, NO_x, $PM_{2.5}$, and etc.) for morning and evening peak hours for pre- (2018) vs. post- (2019) openings of the Express Lanes. Each test site was paired with a control site that was not likely to have been significantly affected by the Express Lane openings (i.e., distant enough from these new facilities), based on comparisons of the demand variability across time of day. The impact of the openings (intervention effect) were derived from a difference-in-difference assessment, which excludes the constant changes at control sites. The traffic volume data and speed profiles were extracted for the test sites at Chastain Road at I-575, Hickory Grove Road at I-75, Indian Trail/Lilburn Road at I-85, and Old Peachtree Road at I-85. A comprehensive QA/QC process was performed before these traffic data were coupled with MOVES-Matrix energy use and emissions rates for modeling. A case study of predicting the CO concentration profiles was also performed at Chastain Road at I-575 using EPA's AERMOD dispersion modeling tool.

Overall, the Express Lanes significantly reduced congestion on the NWC and vehicle speeds increased in some locations by 20 mph during the peak hour period. At the same time, NWC vehicle throughput also increased significantly (an increase of more than 40% in the morning and evening peaks at Chastain Road at I-575, and more than 20% at Hickory Grove Road at I-75 during the morning peak). Either a significant increase in trip generation must have occurred during the morning peak, or congestion reductions were so great that existing traffic diverted into the corridor during the morning peak, or some combination thereof. Given that morning peak traffic is dominated by work and school trips, it seems unlikely that increases in throughput would be related to latent demand, but latent demand increases in the afternoon peak certainly cannot be ruled out. Throughput impacts at other sites were less than 10%.

The impact on energy use and emissions are generally smaller than that on vehicle throughput, and impacts also vary across pollutants (given the variability of MOVES emission rate

relationships with on-road operating conditions). These impacts resulted from changes in on-road operating conditions (speed/acceleration profiles), which further affected the emission rates (grams/second); the congestion relief generally lead to faster travel speeds that are more energy efficient and environmentally friendly. However, increased speeds at Old Peachtree Road at I-85 were high enough that an increase in emission rates was predicted (energy use and emissions to overcome wind load began to increase, which is an embedded relationship in MOVES VSP calculations). Although the openings resulted in a large increase in energy use and emissions at Chastain Road at I-575, these increases may have been compensated by emission reductions on other facilities (i.e., traffic diverted to I-575 from arterial corridors coupled with flow improvements that also reduce energy use per mile of travel and perhaps also from other freeway corridors). Unfortunately, it is not possible to ascertain the net changes in sub-regional and regional energy use and emissions given the data that were available (diversions could not be quantified). The case study of dispersion modeling indicates an increase of maximum concentration from 1.81 ppm to 1.93 ppm, and the maximum hour shifted from 6 to 7 PM to 6 to 7 AM. This change in concentrations is very small and the before-and-after values are both low. The team cannot draw any conclusions on the overall energy use and emissions impact from the Express Lanes until more comprehensive commute activity and traffic operations data can be obtained for nearby arterials and local roads and other freeway corridors. Before-and-after travel behavior studies are needed, if such conclusions are desired.

Acronyms

ABM: Activity-Based Model

AFVs: Alternative Fuel Vehicles

AERMET: Atmospheric Data Preprocessor for Air Quality Models

AERMOD: Air Dispersion Model for Pollutants

ARC: Atlanta Regional Commission

CCTV: Closed-Circuit Television

CO: Carbon Monoxide

EB: Eastbound

EPA: Environmental Protection Agency

FHWA: Federal Highway Administration

GDOT: Georgia Department of Transportation

GHGs: Greenhouse Gases

GP Lanes: General Purpose Lanes

HOT: High-Occupancy Toll Lanes

HOV: High-Occupancy Vehicle Lanes

NB: Northbound

NO_x: Nitrogen Oxides

NWC: Northwest Corridor

$PM_{2.5}$: Particulate Matter 2.5 Microns

PM_{10}: Particulate Matter 10 Microns

QA/QC: Quality Assurance/Quality Control

RFID: Radio Frequency Identification

SB: Southbound

SRTA: State Road and Tollway Authority

TMC: Traffic Management Center

VDS: Vehicle Detection Systems

VOC: Volatile Organic Compounds

WB: Westbound

1. Introduction

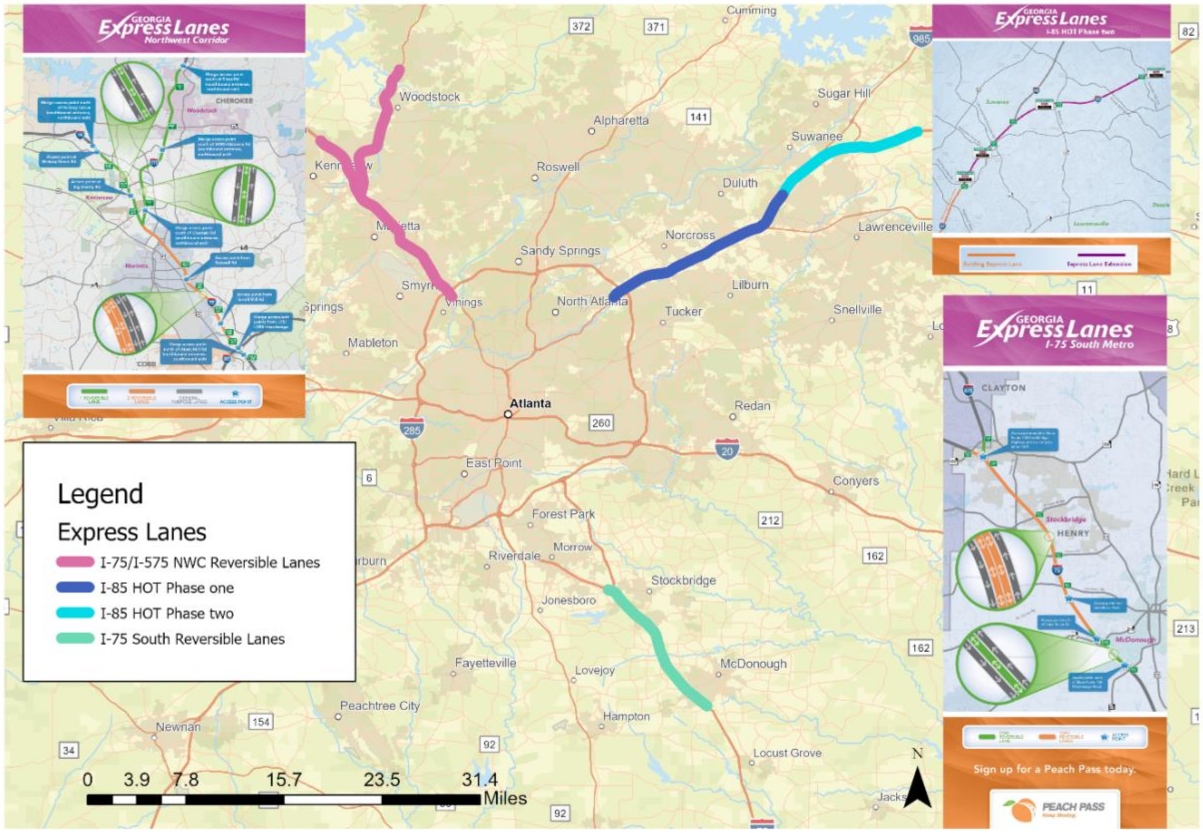
Adoption of managed lanes to provide more reliable travel times and enhance the commuter experience continues to expand in the United States. Managed lanes provide commuters with an option to obtain more reliable travel speeds either by carpooling or paying a toll to use an uncongested facility. High-occupancy vehicle (HOV) carpool lanes, high-occupancy toll (HOT) lanes, and express toll lanes (ETLs), are examples of managed lanes that typically run within or alongside congested Interstate highways. Managed lanes, especially those that use variable tolls to manage demand and prevent congestion from forming on the facility, tend to improve freeway operations and provide reliable travel times during morning and afternoon peak periods (Guensler, 1998; Guensler et al., 2013a; USDOT, 2012; FHWA, 2020).

In the Atlanta Metropolitan area, the Georgia Department of Transportation (GDOT), in collaboration with relevant state and regional transportation agencies, contracts, designs, and constructs managed lane facilities that are part of the planned $16.1 billion managed lanes system (HNTB, 2015; HNTB, 2010). The State Road and Tollway Authority (SRTA) procures the financing for these systems and then operates the tolled transportation facilities within the State. The first priced managed lane facility was an HOV-to-HOV conversion on the I-85 corridor that opened on October 1, 2011. The second facility, the I-75 South Metro Express Lanes, opened about five years later (January 2017). In September 2018, SRTA opened new reversible express toll lanes on the I-75/I-575 Northwest Corridor (NWC), and then extended the existing I-85 HOT Express Lanes north of Atlanta from Old Peachtree Road to Hamilton Mill Road in November 2018 (SRTA, 2019), as shown in Figure 1.

The overall Georgia Managed Lanes Plan calls for $16.1 billion in capital investments on managed lanes facilities (HNTB, 2010; HNTB, 2015). The managed lane system plan identifies the following operational goals and objectives (Smith, 2011):

- Protect mobility in the managed lanes
- Increase vehicle throughput
- Increase average travel speeds and reduce corridor travel times
- Decrease delay
- Decrease travel time variation
- Improve transit on-time performance
- Enhance access to major activity centers
- Increase system efficiency

Atlanta’s Managed Lane Facilities



Source: https://www.srta.ga.gov

Figure 1. Map of Atlanta’s Managed Lane Facilities (SRTA, 2019)

GDOT and SRTA have endeavored to meet these goals through project implementation (corridor selection, design, and operations). Over the past ten years, the state has begun implementing Express Lanes corridors as part of the overall plan. As part of the planning and implementation process, SRTA is committed to monitoring the outcomes of new facilities. In 2010-2012, GDOT and SRTA conducted a before-and-after assessment of the HOV-to-HOT conversion on I-85 to see how the project affected vehicle and person throughput (Guensler, et al., 2013a and 2013b). In preparation for the opening of two new facilities, SRTA funded another 2018-2019 before-and-after study to assess changes in vehicle and person throughput (Guensler, et al., 2021a and 2021b). The four facilities included in the assessment of vehicle and person throughput include:

- I-85 Express Lanes (I-285 to Old Peachtree Road) - This original I-85 Express Lanes corridor runs from Chamblee Tucker Road, just south of I-285, to just north of Old Peachtree Road. The facility is the result of a conversion of pre-existing northbound and southbound HOV2+ carpool lanes into HOT lanes (Guensler, et al, 2013a; Toth, et al, 2012). The original I-85 Express Lanes corridor is about 16 miles in length and includes 13 interchanges, providing entry and egress to the managed lanes (11 off-ramps and 10 on-ramps in the northbound direction and 10 off-ramps and 11 on-ramps in the southbound direction). The SR-316 off-ramp in the northbound direction is located on the left side of the facility, providing Express Lane users a direct exit from I-85. In the southbound direction, drivers coming from the SR-316 HOT lanes merge directly into the left-hand Express Lane on I-85. Lane separation markings are accompanied by physical grooves carved into the pavement within the lane separations, designed to discourage vehicles from crossing into or out of the HOT lanes at non-designated locations. Flexible pylon barriers are also in place in the southbound direction at the I-85/SR-316 weave to discourage illegal weaving into the managed lane (which interferes with the SR-316 traffic entering the facility). The original I-85 Express Lanes (HOT lanes) opened on October 1, 2011.

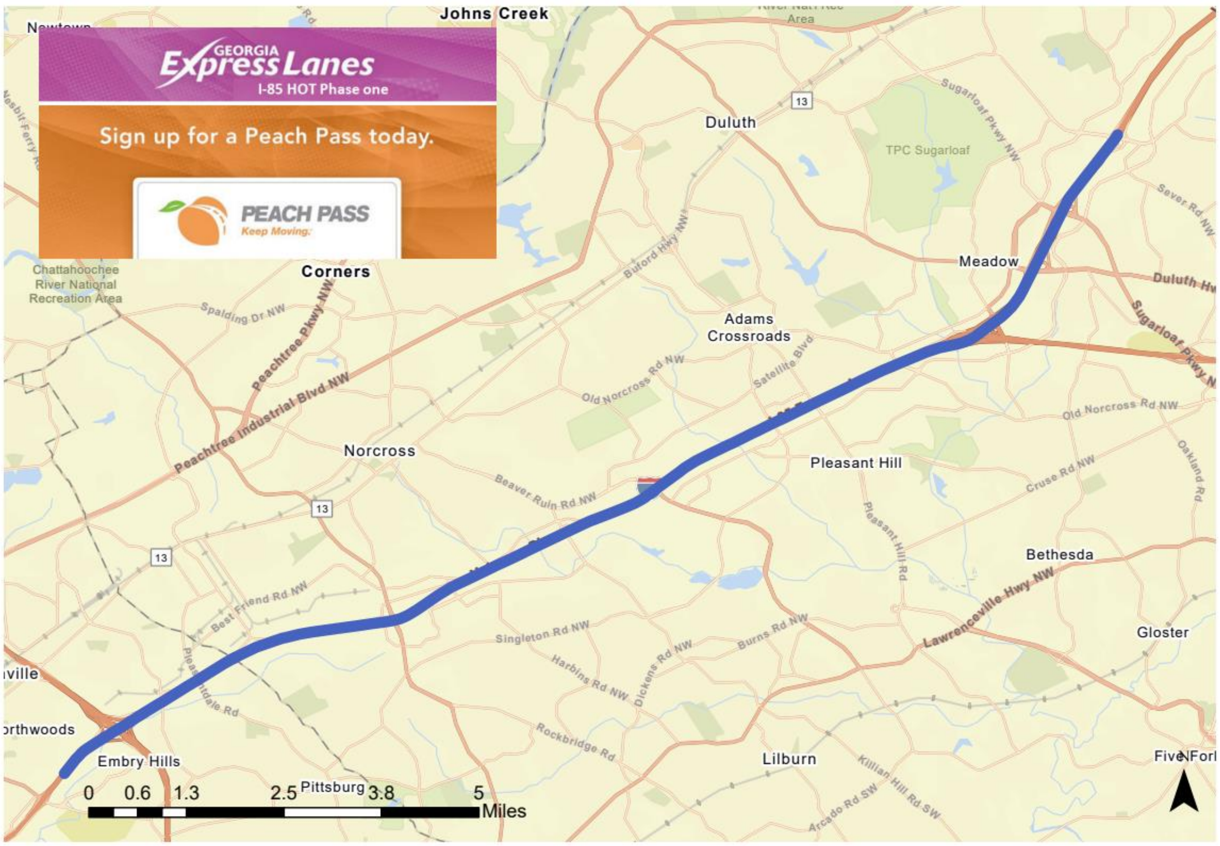


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Figure 2. I-85 Express Lanes (SRTA, 2019)

- Northwest Corridor Express Lanes (along I-75 and I-575) - The Express Lanes on the I-75/I-575 Northwest Corridor consist of about 30 miles of reversible toll lanes along I-75 from Akers Mill Road to just past Hickory Grove Road, and along I-575 from I-75 to just past Sixes Road. Two Express Lanes run parallel to the I-75 between I-285 and the I-575 split, at which point single lanes continue northward along each Interstate leg. Hence, one Express Lane was added along I-75 north to Hickory Grove Road and one Express Lane was added along I-575 north to Sixes Road. The I-75/I-575 Northwest Corridor

Express Lanes opened in September 2018. The NWC Express Lanes do not include an occupancy exemption and all users of the facility pay a toll, with few exemptions.

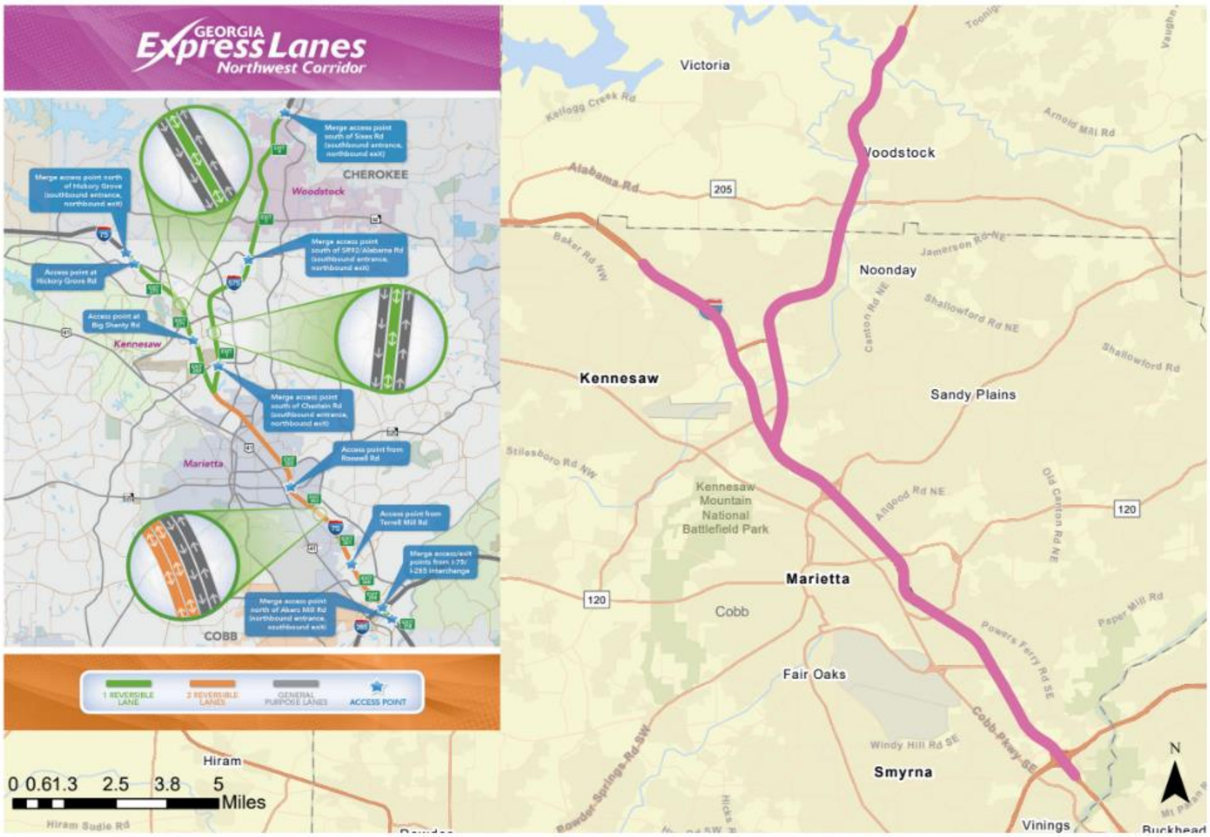

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Figure 3. Northwest Corridor Express Toll Lanes (SRTA, 2019)

- I-85 Express Lanes Extension (HOT lanes running from Old Peachtree Road to Hamilton Mill) - The extension of the I-85 Express Lanes consists of new lane construction located entirely within Gwinnett County. About ten miles of newly constructed lanes begin north of the existing I-85 Express Lanes at Old Peachtree Road and extend just past Hamilton Mill Road. Auxiliary lanes constructed between on-ramps and off -ramps allow drivers to merge into traffic and help prevent bottlenecks caused by drivers attempting to enter or exit the freeway. All of the same rules that apply on the original I-85 Express Lanes apply to the I-85 Express Lanes Extension. SRTA charges separate tolls on the I-85 Express Lanes and I-85 Express Lanes Extension; drivers may enter or leave the facility at the transition between facilities. The I-85 Express Lanes Extension opened in November 2018.

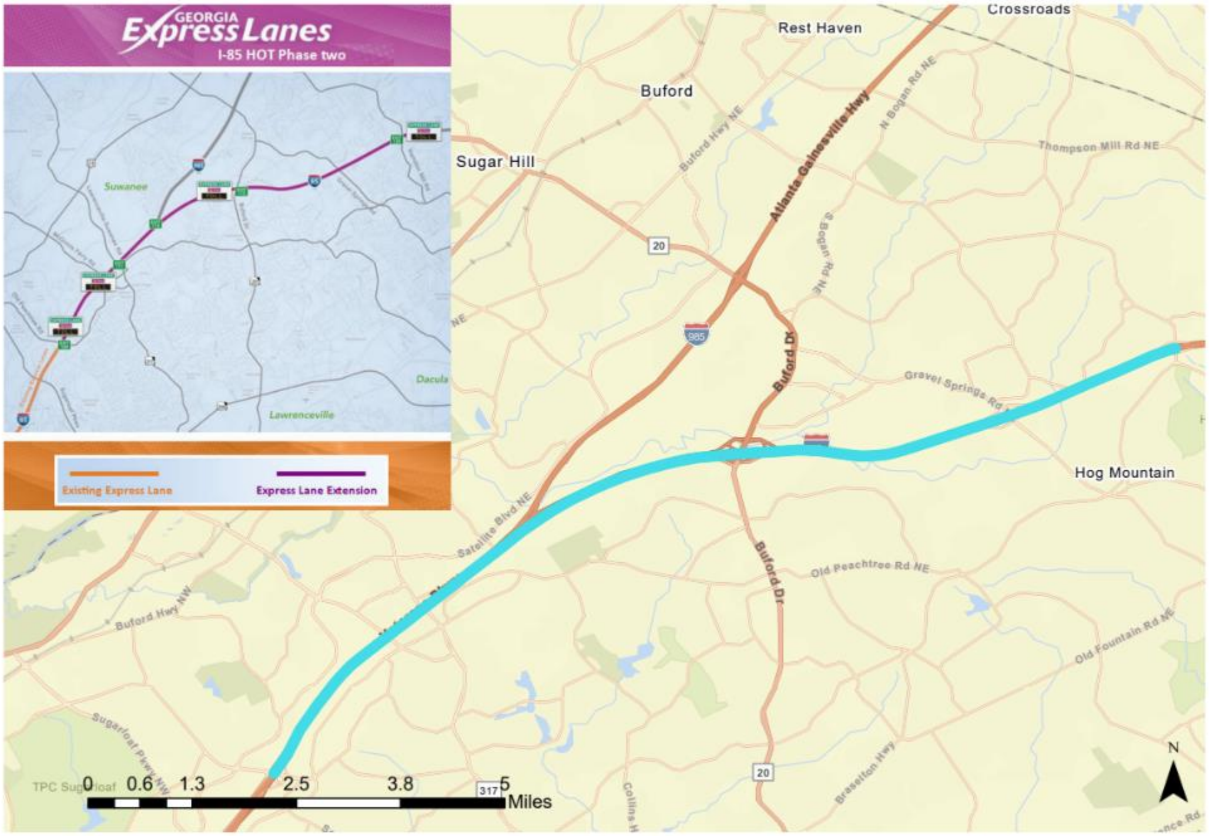

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Figure 4. I-85 Express Lanes Extension (SRTA, 2019)

- I-75 South Metro Express Lanes - The I-75 South Metro Express Lanes consist of about 12 miles of reversible toll lanes constructed within the center median of I-75, south of Atlanta. The lanes serve inbound traffic to Atlanta in the morning peak and outbound traffic in the afternoons, adding new capacity to the pre-existing general purpose lanes. The facility runs from McDonough Road (State Route 155) in Henry County to Stockbridge Highway (State Route 138) in Clayton County (SRTA, 2019). The I-75 South Metro Express Lanes opened in January 2017 and do not include an occupancy exemption; all users pay a toll, with few exemptions. This research does not assess changes on the I-75 South Express Lanes (COVID prevented collection of 2020 data).

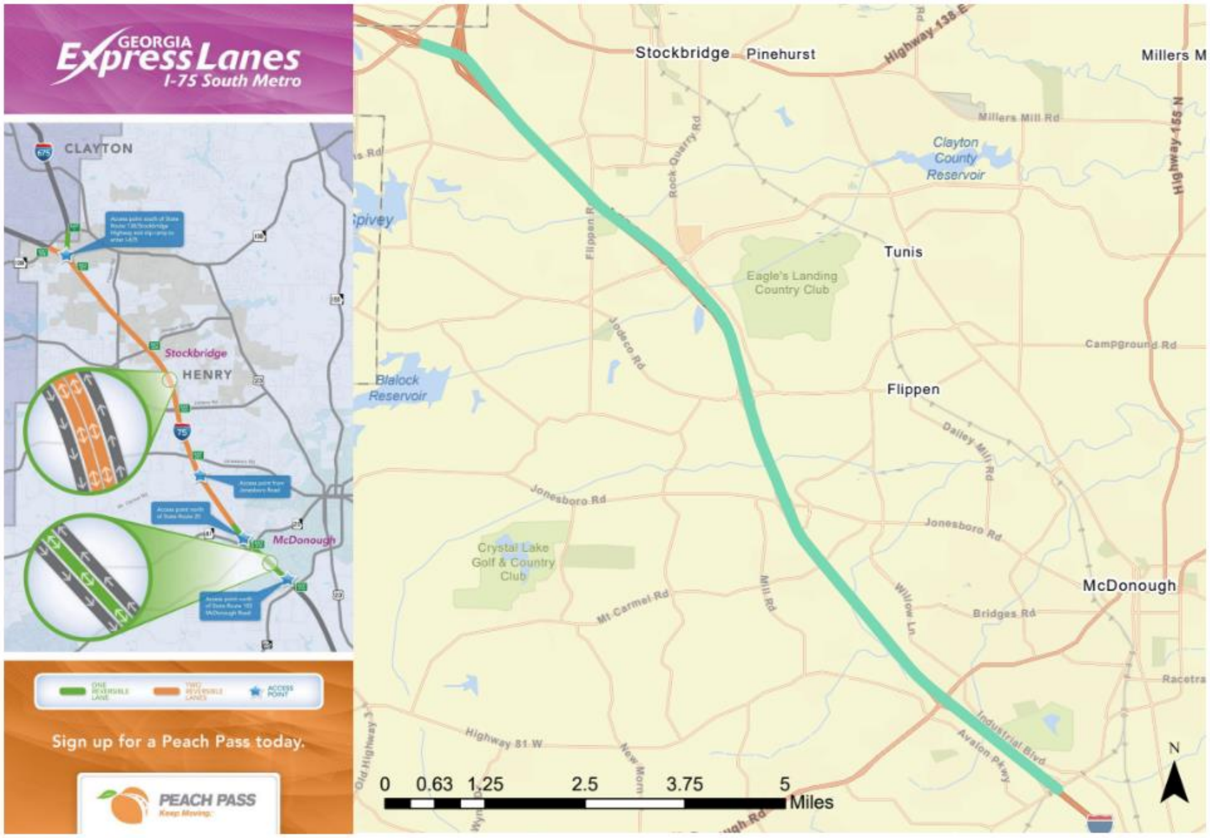

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Figure 5. South Metro Corridor Express Toll Lanes (SRTA, 2019)

All four managed lane corridors collect tolls that change dynamically (on a timetable or via analysis of sensor data) so that toll price responds to congestion. As demand for use of each of these lanes increases, the toll increases to ensure that managed lane demand remains below capacity and users experience reliable trip times. To use any of the Express Lanes, vehicles must have a Peach Pass® account and display a Peach Pass® toll tag inside the front windshield (SRTA, 2019). The goal of pricing is to manage demand and prevent congestion formation (keeping speeds >45 mph). The system demonstrates interoperability with the tolling systems of both North Carolina and Florida. A recent development is the addition of compatibility with the E-ZPass® electronic toll collection system, although E-ZPass® integration was not yet implemented at the time this project was performed (E-ZPass® Group, 2023). Vehicles with 3+ axles and/or 6+ wheels (i.e., light-heavy-duty vehicles or larger) may not use any of the priced managed lanes. Registered buses, 3+ person carpools, vanpools, motorcycles, emergency vehicles, and dedicated alternative fuel vehicles (AFVs) with the proper AFV license plate (which excludes all hybrid electric vehicles) may use both of the I-85 facilities toll-free. However, on the I-75 Northwest Corridor and I-75 South Metro express lanes, only state-registered Xpress and CobbLinc buses (CobbLinc, 2021; GRTA, 2021), vanpools, and law enforcement vehicles may use the lanes toll-free (carpools, motorcycles, and AFVs pay the full toll). All vehicles using the Express Lanes must display a registered Peach Pass toll tag and have a valid account.

The I-85 facilities employ dedicated managed lanes in each direction. That is, users have access to a northbound and southbound Express Lane all day, every day. However, the NWC and South Metro Express Lanes are reversible, serving traffic inbound to Atlanta during the morning peak period and outbound traffic during the afternoon peak period. At around noon, SRTA closes the inbound access points, waits for all traffic to clear, conducts a drive-through safety check to ensure that the lanes are completely clear, and then opens the outbound access points for afternoon commute traffic. Hence, the latest Express Lane additions have added significant lane capacity to the pre-existing general purpose lanes to handle peak period traffic.

The managed lanes operations rules are not the same on each corridor. For example, the I-85 Express Lanes (including the original HOV-to-HOT conversions stretch and the extension) are free for registered carpools (carrying three or more occupants), motorcycles, transit vehicles, emergency vehicles, and Alternative Fuel Vehicles (AFVs) with the proper license plates. However, the Northwest Corridor and I-75 South Metro facility do not provide toll-free travel to any of these vehicles. As noted earlier, only registered Xpress and CobbLinc buses and state-registered vanpools are provided with toll-free trips on these two corridors. Using any of the four facilities requires a Peach Pass is now required. The Peach Pass radio frequency identification (RFID) tag is used for electronic toll collection. Even vehicles that are exempt from the toll on any facility require the presence of a Peach Pass in the vehicle. The passage of each exempt vehicles is recorded via readings of the Peach Pass tag number, but the vehicles are not charged if they are confirmed by back-office routines to be exempt.

FHWA’s transportation performance management goals include congestion reduction, system reliability, freight movement and economic vitality, and environmental sustainability (FHWA, 2021). The metrics used to assess system performance have moved toward developing a better understanding of vehicle mix and associated vehicle occupancies under reliable conditions. According to FHWA, the use of local occupancy data will be highly recommended in meeting these metrics rather than the use of national defaults by vehicle class (the use of national defaults may not be to the agency’s advantage). In addition, FHWA has stated that there will likely be an increased focus on transit occupancy and alternative modes in urban areas. With respect to freight operations, vehicle classification data and freight hauling data will need to be coupled with freeway performance data in the future.

Most studies of newly opened managed lanes typically focus on a comparison between the before-and-after state. However, simple before-and-after comparisons cannot always ensure that the actual marginal impact of the new facility opening is accurately assessed (Xu et al., 2017; Devarasetty et al., 2012). For example, a difference in traffic volumes, speeds, and resulting pollutant emissions in before-and-after scenarios might have resulted from a change in regional economic strength, increased gasoline costs, or even the impacts of a pandemic, rather than the opening of the new facility itself. Before-and-after analyses often fail to capture changes in travel behavior that are caused by factors other than the facility impact alone (i.e., there is a need to introduce control variables into the analyses). A comparison between a real-world scenario against a scenario that might would have occurred in the absence of the intervention, is often implemented in other environmental projects (Henneman et al., 2017), and can be used to help assess the impact of the Express Lane facilities by excluding constant differences ("natural" change) observed across relevant control locations.

This report summarizes the assessment of the energy use and emissions impact of the Express Lane facility openings, using the findings and data from the 2019-2020 vehicle and throughput assessment (Guensler et al. 2022a). The impact of the I-75/I-575 NWC and I-85 Extension are evaluated in energy and environmental aspects, including impacts of vehicle energy uses, Greenhouse Gas (GHGs) emission and criteria pollution emissions (CO, VOC, NO_X, $PM_{2.5}$, PM_{10}) modeling. A case study of near-road air quality predictions was performed at Chastain Road at I-575 based on the roadway network from the Activity-Based Model (ABM) from Atlanta Regional Commission (ARC). The before-and-after assessment was performed based on comprehensive data collection for the counterfactual comparison between the real-world scenario and the scenario which would have occurred in the absence of the intervention (i.e., using control sites that were not influenced by the openings). A state-of-the-science tool that combines MOVES-Matrix and AERMOD (Lu, et al., 2023) was also used to model the resulting downwind concentration profiles for the NWC facility. This research effort is analytical in nature, and methods remained consistent throughout the entirety of the study.

1.1 Data and Methodology

The team adopted the synthetic control methodology to account for factors other than the opening of the Express Lane facilities (e.g., growth of vehicle ownership) that might influence vehicle throughput and resulting energy use and emissions, by developing control sites which indicate the change in traffic operations in the absence of the opening of the Express Lane facilities. That is, the marginal impact (intervention effect) of the Express Lane opening can be assessed by excluding the constant differences derived from comparable locations that share similar patterns of demand variability (i.e., control sites), as shown in Figure 6.

The study primarily focuses on designated test and control sites; however, the influence of the Express Lanes might extend beyond these specific locations. Given the noted reduction of congestion when the I-75/I-575 NWC facility opened, it now appears likely that traffic from parallel facilities and the shoulder of the peak was drawn into the corridor, increasing vehicle throughput. If this is true as expected, the energy use and/or emissions increases noted on the NWC will have been partially or even fully offset by energy use and emissions reductions on the corridors from which traffic volumes were drawn (i.e., reducing congestion on those alternative routes). Without comprehensive data covering parallel arterials and highways, it was not possible for the team to conclusively verify sub-regional or regional changes in system efficiency, congestion reduction, energy use, or pollutant emissions.

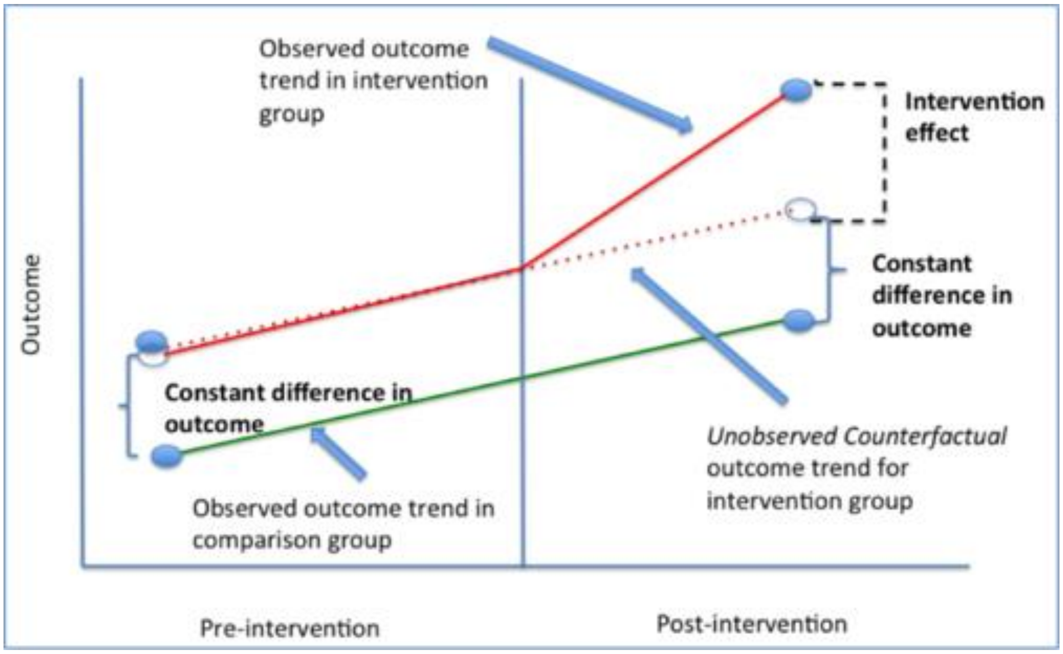


Figure 6. Counterfactual Comparison of Intervention (Columbia University Mailman School of Public Health, 2013)

1.1.1 Traffic Operation Profiles: GA NaviGAtor Data

The Georgia NaviGAtor system, housed in the GDOT Traffic Management Center (TMC), monitors vehicle speed and throughput data for the I-75 and I-85 corridors (GDOT, 2023). The NaviGAtor system monitors more than 220 miles of freeway in Atlanta's metropolitan area, primarily for use in dispatching emergency service crews and collecting data that can be used to improve system safety and efficiency. The Georgia NaviGAtor system is composed of video monitoring systems, communications systems, and advanced signage. Video-based vehicle detection systems (VDS) are located at monitoring stations approximately every 1/3-mile along freeways throughout the region. A machine vision process counts vehicles that traverse the video system's field of view and generates the VDS data. The change in pixel colors occurring within a vehicle detection zone in the video field of view indicates the entry and departure (i.e., the temporary presence) of a vehicle within the detection zone. By establishing two detection zones at a known distance separation, the system also provides estimates of vehicle speed. Navigator data include: traffic volumes in the managed lane, traffic volumes in each general purpose lane, vehicle speeds in the managed lane, and vehicle speeds in each general purpose lane. Some machine vision systems also perform vehicle classification (light-duty vehicles, heavy-duty vehicles, etc.), but classifications were not available for the specific study areas. Hence, the team performed manual observations of vehicle classification.

The NaviGAtor data flow to the Georgia Tech NaviGAtor archive through a remote GDOT TMC network monitoring station in the transportation research laboratory at Georgia Tech. The monitoring station is isolated from the Georgia Tech network for security purposes. The VDS data feed includes traffic volumes and spot speed data, by lane, at 20-second resolution. The research team manages an analytical archive of the TMC data, including the raw and processed 20-second data, aggregation of data to 5-minute bins, 15-minute bins, and hourly volumes. The Georgia Tech team used 2018 and 2019 NaviGAtor data for this analysis. The data are archived in near real time, in 20-second bins. Figure 7 and Figure 8 provide an overview of the NaviGAtor system at the time the study was performed, which consisted of:

- Approximately 1,645 VDS stations along major interstates around Atlanta (approximately 1/3-mile)
- About 500 full-color CCTV cameras along major interstates around Atlanta (approximately 1-mile)
- A total of 2,958 cameras (2,208 in metro Atlanta and 750 in other areas) available online (some cameras listed online may be temporarily unavailable)
- A total of 208 changeable message signs (172 in metro Atlanta and 36 in other areas)
- More than 160 ramp meters
- The Georgia Tech archives of historical GA Navigator data for 2016 to 2019 include about 1,950 stations (devices)

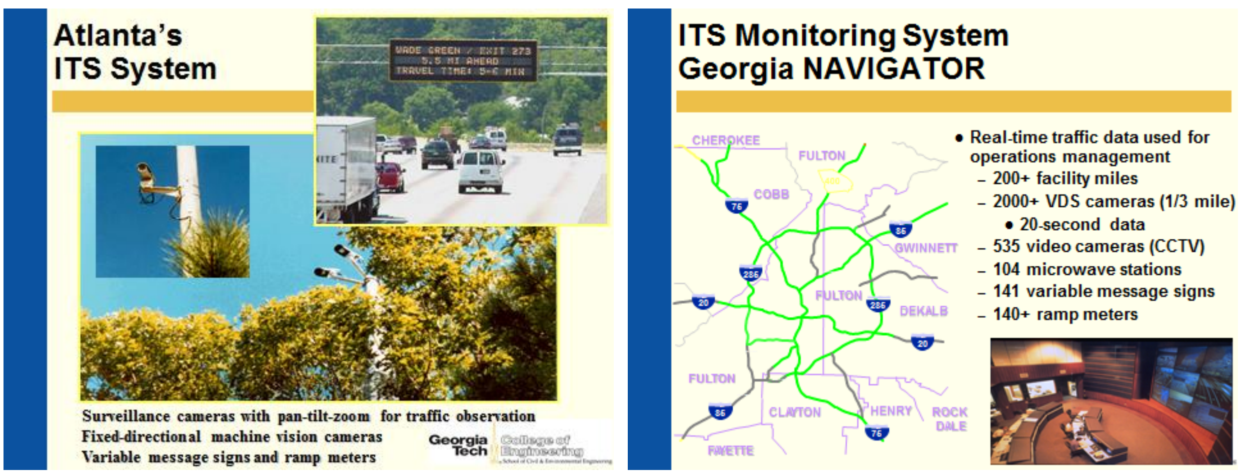


Figure 7. Overview of the NaviGAtor System

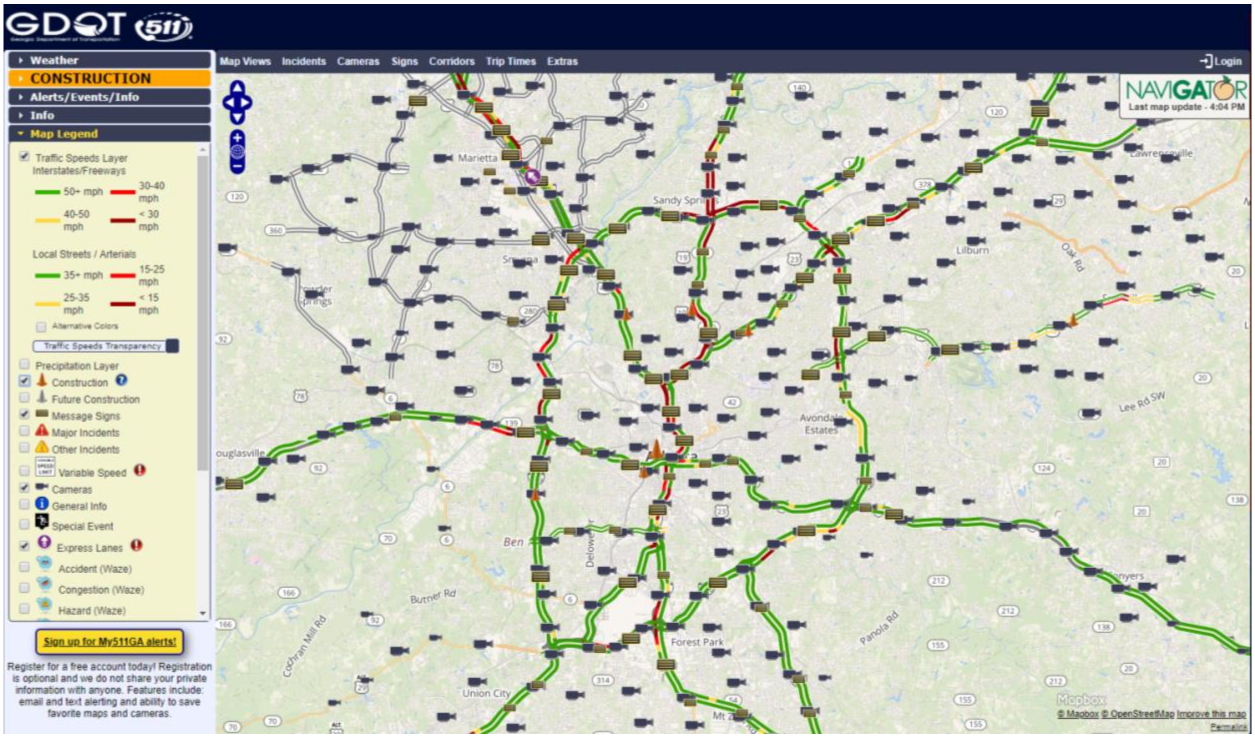


Figure 8. NaviGAtor Web Interface

As discussed earlier, the Georgia Tech data archive receives a direct feed from the NaviGAtor system. Because each NaviGAtor device only covers a limited distance of road, it is important to select the appropriate devices to represent the traffic operations at or near the observation sites, so that the traffic operating data can be properly integrated with the field observed occupancy profiles (for example, to exclude the impact of downstream ramps that are not included in the field occupancy collection). The research team selected the NaviGAtor devices for all observation sites based on the NaviGAtor device list provided by GDOT, which includes the information of primary road, cross road, direction, mileage marker, etc. for every device, in additional to a short description of the device location (for example, “CUMBERLAND BLVD W AT I-75”, or “EXT RMP TO JONESBORO RD”). The descriptions include a short explanation of the road type, primary road and cross road, and helps locate the devices with respect to its position compared to the cross road (for example, “S OF CHASTAIN RD” vs. “N OF CHASTAIN RD”).

Although the device list provides the latitude and longitude information, these data are not always accurate, so the research team selected potential NaviGAtor devices starting with the short descriptions and through-the-lens camera views. Multiple potential NaviGAtor devices were selected for both bounds at each observation site, and the exact locations of these devices (i.e., the poles onto which NaviGAtor devices were installed) were verified based using mileage marker information (coupled with the primary road). The NaviGAtor device pole for Northbound at Chastain Road of I-575 is shown as an example in Figure 9 (Google Earth, 2020).

Figure 9. Locating the NaviGAtor Device #3471, Northbound, Chastain Road at I-575. Screenshots from Satellite Map and Street View of Google Earth.

Each NaviGAtor device captures the traffic flow of one or multiple lanes, but not necessarily for all lanes at that location. For example, after the opening of the Express Lane of I-75/575 NWC, new NaviGAtor devices were deployed for the managed lanes (i.e., separate from the existing GP-lane devices). Therefore, for Chastain Road of I-575 and Hickory Grove Road of I-75, two devices (one existing device for GP lanes, and one lately deployed device for Express Lanes) were selected, while one device was selected for other sites.

The Old Peachtree Road and Hamilton Mill Road at I-85 were beyond the coverage of NaviGAtor devices in 2018 (new devices deployed in 2019 by GDOT as an expansion of NaviGAtor coverage); hence, no devices could be selected for these two sites to provide baseline volumes. The research team selected Sugarloaf Road at I-85 (closest available device to observation site at Old Peachtree Road) as a replacement to represent Old Peachtree Road. No available device close enough could be selected as replacement to represent the Hamilton Mill Road at I-85 in 2018 (and therefore a before-and-after assessment cannot be conducted since only data of 2019 are available).

The research team processes the 20-second VDS data through a series of quality control measures to identify and eliminate highly improbable values. Gaps in real-time data do occur, and these gaps are attributable to several different factors, such as sensor failures, data communications interruptions, etc. Georgia Tech researchers also process the 20-second data to impute missing data. After filtering and imputation, 20-second data are re-aggregated to five-minute bins, and one-hour bins, and are retained in the separate analytical archive for use in research activities.

1.1.2 Vehicle Speed Variability

As presented in the previous assessment report (Guensler, et al., 2013a), Figure 10 provides an example plot of the average daily free-flow speeds at one of the detection stations between October 2010 and May 2012. The sudden shifts in the data across all lanes (December 2010 and October 2011) indicate potential calibration changes in the data. Recalibration can also affect the accuracy of any imputed data from adjacent stations. To prevent the propagation of errors, cross-station imputation strategies were not employed. Imputation was only performed over time. For example, for a 5-minute aggregate, if data was available only in 10 out of the fifteen 20-second time intervals, the count data was simply scaled by 15/10 to adjust for the missing data. The average speed was computed from the 10 data points that were available. If no data were available in an entire 5-minute period, these missing points were accounted for in a scaling factor when aggregated up to a larger period such as 15 minutes or an hour. Any NaviGAtor data used in vehicle throughput analyses and corridor speed assessments need to be assessed for potential changes in equipment calibration over time. The team calculated the free-flow speed per day based on the speed-flow rate relationships, and the daily average free-flow speed were plotted against time. The time series plots were visually examined to identify any day-to-day shift (which indicates re-calibration efforts). In this study, multiple NaviGAtor data collection locations were assessed, and no recalibration was identified during the data collection period.

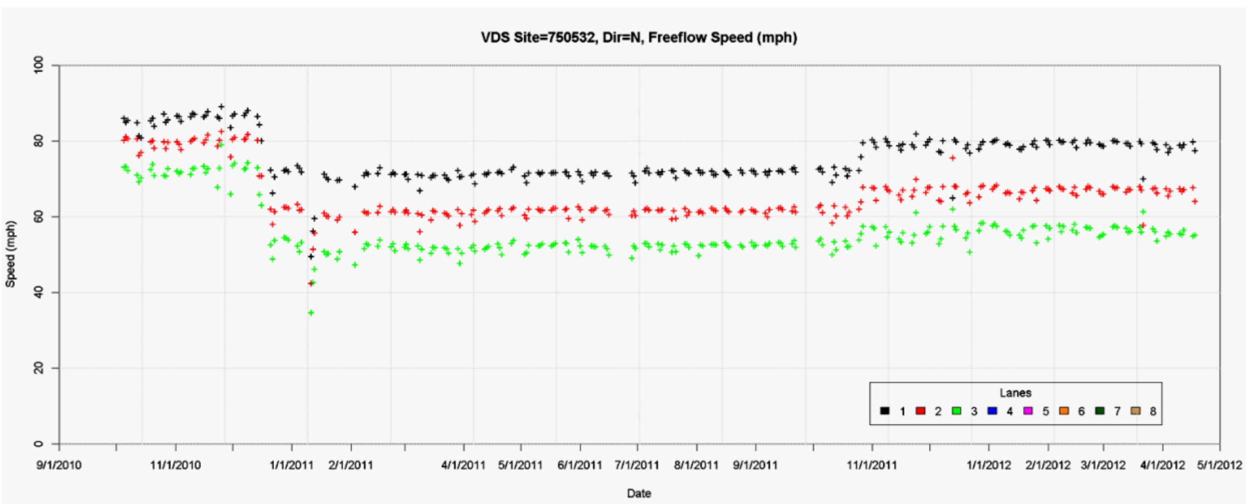


Figure 10. Time Series Plot of Daily Averages for Free-flow Speeds

1.1.3 Quality Assurance/Quality Control (QA/QC)

The fundamental relationship between speed and flow is employed to filter VDS data in the QA/QC process. Highly improbable 20-second paired speed and volume data points are removed from the data set and replaced with null values, using a series of data filtering scripts applied to the raw data feed. Null values are imputed in a later step.

Video detection data quality varies as a function of field configuration, including height of device, camera angle, presence of obstructions (e.g., blocking by overpass), sunlight level, sun angle, rain, etc. Hence, improper camera setup, poor camera angles, weaving activity in the detector zone, and even fleet composition (because large vehicles can block the detection of smaller vehicles) can affect data accuracy (Castrillon, et al., 2012; Grant, et al, 1999).

An appropriate calibration of the camera field-of-view is essential to estimate the vehicle length and vehicle speeds (Grant, et al., 1999). The calibration provides a 3-D measurable perspective to a 2-D video image by establishing ground distances relative to the view of the camera. Calibration lines placed parallel and perpendicular to the travel lanes form detection zones for each lane in the image. Single detection zones use distance and estimated vehicle length to estimate speed, while dual detection zones use the distance and time separation between detections to estimate speed. Any improper or obsolete calibration could lead to errors in volume count and vehicle speeds; hence, re-calibration of detectors by GDOT staff during the middle of a study could create problems in comparing older data to newer data. Fortunately, re-calibration events can usually be identified by examining the continuity of the average free-flow speed/volume profiles over time (Guensler, et al, 2013a). As noted earlier, no recalibration events were identified in the QA/QC review of NaviGAtor data used in this study.

False detection and missing vehicles can still happen even after careful calibration of the detection zones. For example, large vehicles can block the field of view, and inclement weather conditions can lead to poor vehicle visibility, causing traffic volumes to be under-counted. On the other hand, weaving may lead to a duplicate identification of the same vehicle and cause over-counting of traffic volumes, or lead to missing vehicles (Guensler et. al, 2021a). Other factors, such as movement of the camera (which can happen when cameras installed on overpass bridges shake as vehicles travel across the bridge), or communication error during data transfer, may also lead to errors or loss of raw NaviGAtor data.

Because raw video feeds are typically not archived, QA/QC can often be conducted only by analyzing the resulting speed/volume profiles. Because the detector placement and camera configuration vary for each site, cross-validation strategies are usually impractical given the lack of archived video data. Therefore, the QA/QC is best when based upon the calibration of speed/volume profiles at each specific site. The following steps are used to clean the NaviGAtor data:

Step 1: Collect Free Flow Data:

Because the speed data are obtained from video processing, sudden shifts in the data may be due to the potential calibration changes. Free-flow conditions are used first to the assess speeds estimated by the machine vision systems. The research team uses laser guns to collect accurate free-flow speed data for each lane at each site (one hour for each lane and each site).

Step 2: Aggregate Laser Gun Data:

The team aggregates the laser gun speed data collected in Step 1 into five-minute bins, and identifies the appropriate free-flow speed for each lane at each site. Here the notation v_{sl}^{m} represents the measured free-flow speed of site s and lane l.

Step 3: Aggregate Navigator Data:

For each site and each lane, the NaviGAtor speed and volume data are aggregated from raw 20-second readings to five-minute bins. Here the notation v_{sl}^{n} represents the observed NaviGAtor free-flow speed of site s and lane l.

Step 4: Calculate Scaling Factor:

A scaling factor f_{sl} for site s and lane l is defined as the ratio of v_{sl}^{m} and v_{sl}^{n}, i.e., $f_{sl} = v_{sl}^{m}/v_{sl}^{n}$. The scaling factor essentially calibrates the speeds estimated by the machine vision system to the accurate speeds measured by the laser guns.

Step 5: Apply Scaling Factor:

Use the scale factor f_{sl} from Step 4, scale the 20-second raw NaviGAtor data by multiplying all NaviGAtor speed with f_{sl} based on the site and lane.

Step 6: Filter Data:

The filter criteria are applied to the scaled data (20 seconds interval) in Step 5 (Guensler, et al., 2013a). Figure 11 shows an expected speed-flow plot (example from the inside lane at Chastain Road at I-575 Northbound). The exclusion zones (rectangular area at top of image, rectangular area on the right side of the image, and triangular area on the bottom of the image, all of which are also color-coded in coral) represent speed-flow regions where no data points are expected to be observed, based upon fundamental traffic engineering concepts. A conservative approach is adopted, and only the data in the light coral zones are identified as invalid and removed from consideration. The empirical thresholds set constraints on 1) high speed larger than 98 percentile of the data (i.e., 110 mph), 2) anti-intuitive high volume of 3,600 vehicles per hour per lane (i.e., more than one vehicle per second), and 3) large density at low speed (larger than 230 vehicles per mile). The conditional logic and the thresholds used in data filtering are provided in Table 1. In general, after QA/QC filtering, about 97% of the data will have passed the validity tests and remain available for analysis.

Step 7: Aggregate Filtered Data:

Aggregate the filtered 20-seconds data from Step 6 to 5-mins interval, plot and verify it is ready to use. Imputation was only performed on the time scale. For example, for a 5-minute aggregate, if data was available only in 10 out of the fifteen 20-second time intervals, the count data was simply scaled by 15/10 to adjust for the missing data. The average speed was computed from the 10 data points that were available. If no data were available in an entire five-minute period, these missing points were accounted for in a scaling factor when aggregated to a larger period (i.e., one hour). The imputation followed the same methodology used in the previous projects (Guensler, 2013a and 2021a).

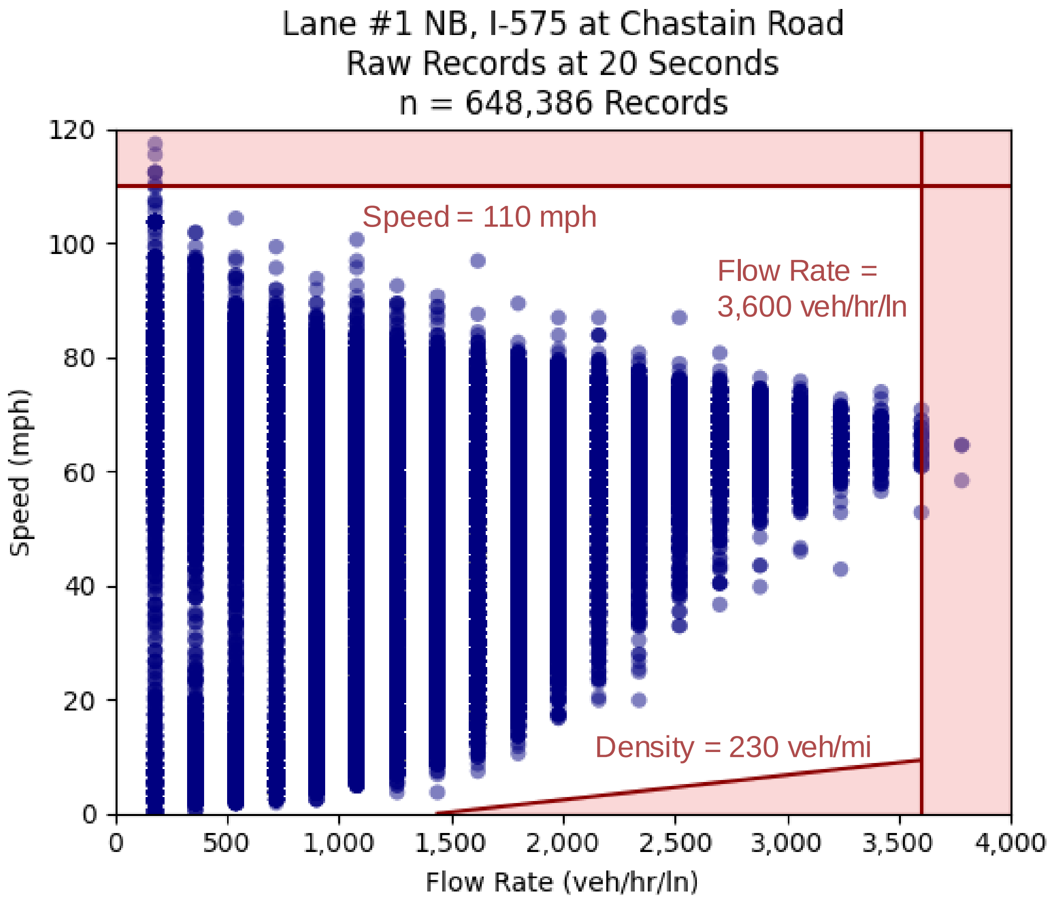


Figure 11. Data Validity Zones in a Speed-Flow Plot

Table 1. QA/QC Screening Threshold Values

Threshold Values		
Volume (vehicles/20sec)	**Speed (mph)**	**Density (vehicles/mi)**
(Two conditions must be true to be declared invalid)		
Zero (= 0)	Zero (= 0)	Zero (= 0)
(All conditions must be true to be declared invalid)		
Not Low (>8)	All	Too High (>=230)
Too High (>= 20)	All	All
All	Too High (> 110)	All

The GDOT lane numbering rule marks the inside lane (closest to the center median in the direction of travel) as Lane #1, and the lane number increases from inside to outside. The research team verified the speed-flow rate relationships across the lanes to make sure lanes are numbered correctly, as an additional step to the QA/QC process. The inside lane is the fast lane and is expected to have the largest free flow speed and the largest capacity among all lanes. When the managed lane is protected and separated from GP lanes by concrete barriers, such as in Chastain Road at I-575 NWC (2019 only) and Hickory Grove Road at I-75 NWC (2019 only), the inside GP lane is considered as the fast lane. Lane-by-lane speed-flow rate diagrams were used to make sure lanes are numbered correctly, with an example of Northbound of Chastain Road at I-575 (2018) presented in Figure 12.

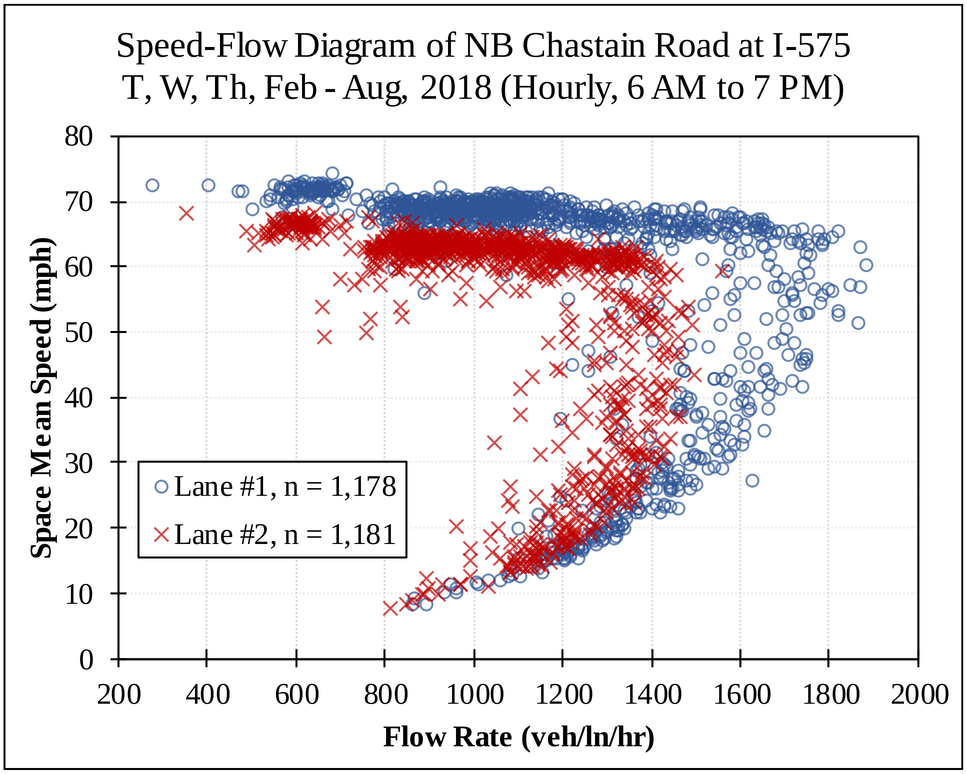


Figure 12. Speed-Flow Diagram, Aggregated at One Hour, Northbound, Chastain Road at I-575, Pre-Opening (2018), Day Time (6 AM-7 PM)

1.1.4 Test Sites and Control Sites

The net change in throughput and changes in emission rates as a function of traffic operations, both of which affect resulting emissions and pollutant concentration profiles, are also affected by regional changes in vehicle ownership over time (unrelated to the opening of the Express Lane facilities). These constant changes may also vary from site to site (and vary between inbound vs. outbound traffic at the same site), and need to derived from equivalent locations that share similar patterns of demand variation over time (control sites). Control sites are specific locations that were: 1) unaffected by the factors being studied (in this case, the Express Lane openings) and 2) comparable with the test sites in terms of traffic demand patterns for gauging the 'natural' changes in throughput and speed.

Identifying "natural" growth in traffic demand is inherently challenging, due to the spatial and temporal variability of traffic conditions and the influence of changes in sub-regional land use, employment, demographics, etc., which are not tracked adequately in time and space (at a high-enough resolution) to assess an impact over a one-year period. While every effort was made to select control sites with similar traffic demand and operating speed variability, some pairings may be less precise than others. These limitations have been transparently reported; however, the research team believes that the results remain valid and provide meaningful insights into corridor-specific impacts under this study's scope.

The control sites from major Interstate/State highway corridors need to be immune from the impact of the opening (i.e., distant locations), and need to have similar variability of traffic operations across time of day so that they can be paired with the test sites (similar trends of demands). The throughput and speed changes at a control site are assumed to represent the constant differences at the paired test site ("natural" change), if the test site had not been influenced by the opening.

The twelve control sites from various major commute corridors across the metro area of Atlanta (I-75, I-85, I-75/I-85, I-285, and GA-400) are shown in Table 2, which are all far enough from the openings to be uninfluenced, as shown in Figure 13. It is worth noting that although Shallowford Road at I-85 is located on the same corridor with the I-85 Express Lane Extension, the team concluded it was not significantly impacted by the Extension. Since Indian Trail/Lilburn Road (which is much closer to the Extension than Shallow Ford Road) was hardly influenced by the Extension, as indicated by the before-and-after comparison (Guensler et al. 2021), the team concluded that Shallowford Road at I-85 can be safely selected as a control site. The GA NaviGAtor devices at each control site provide volume and speed profiles of both travel approaches and can be used to represent either the morning and evening peak hours.

Table 2. Synthetic Control Sites and the Corresponding Corridors

ID	Site	Peak Session for Inbound Traffic	Corridor
1	Moores Mill Road at I-75 NB	PM	I-75
2	Moores Mill Road at I-75 SB	AM	I-75
3	Wieuca Road NE at GA-400 NB	PM	GA-400
4	Wieuca Road NE at GA-400 SB	AM	GA-400
5	Shallow Ford Road at I-85 NB	PM	I-85
6	Shallow Ford Road at I-85 SB	AM	I-85
7	University Avenue at I-75/I-85 NB	PM	I-75/I-85
8	University Avenue at I-75/I-85 SB	AM	I-75/I-85
9	North of Wilkinson Parkway at I-285 NB	AM	I-285
10	North of Wilkinson Parkway at I-285 SB	PM	I-285
11	Buford Highway at I-285 EB	PM	I-285
12	Buford Highway at I-285 WB	AM	I-285

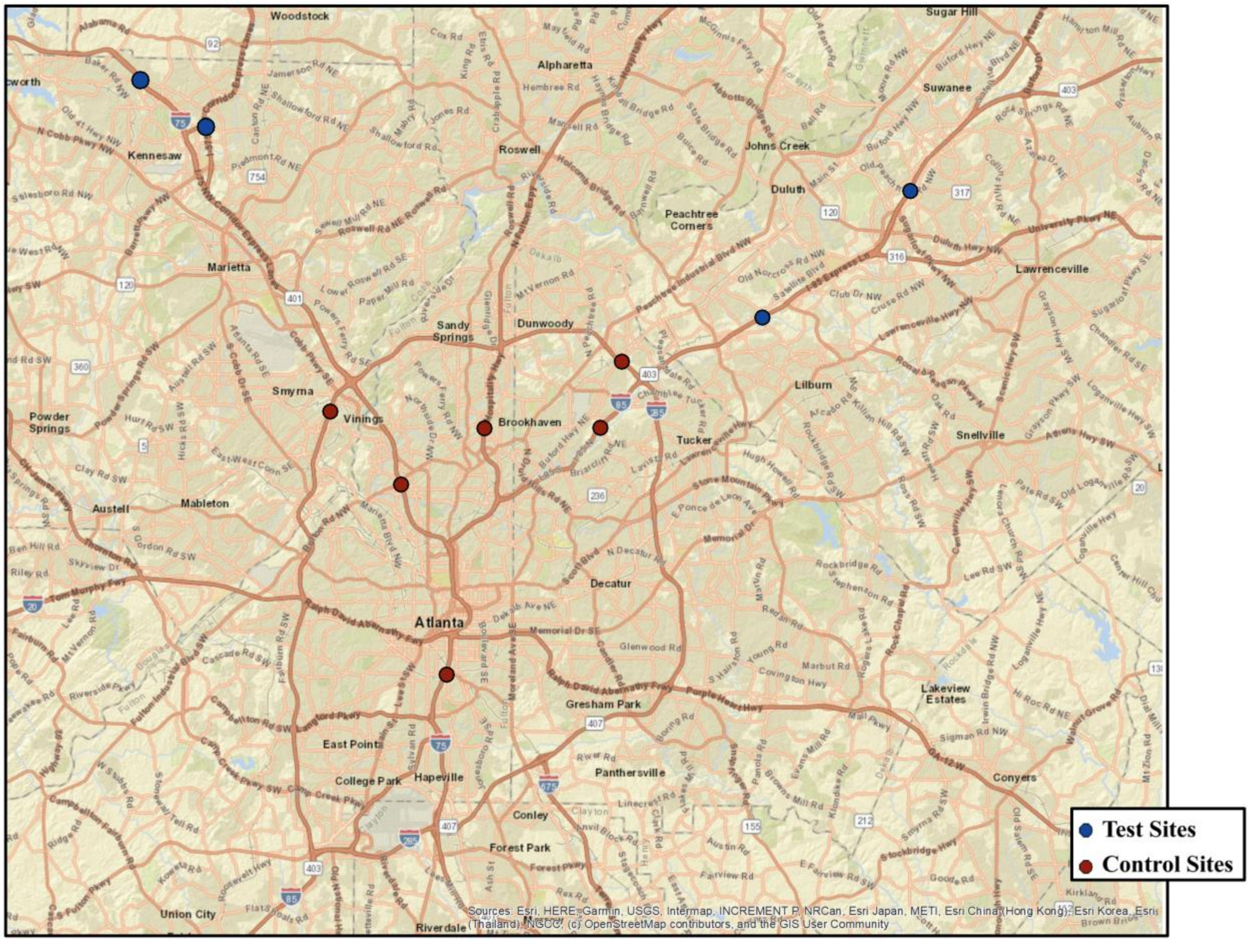


Figure 13. Map of the Test and Control Sites

Each test site was paired with one control site based on a manual comparison of the variability of average speed across hours (time of day). The variances of average speed (aggregated to one-hour intervals) for each site (test and control sites) was manually reviewed, and the control site that best pairs with each test site was selected based on visual examination. This study assumes that similar variabilities patterns indicate similar types of demand (e.g., commute, shopping, etc.), and similar throughput (and speed) changes from 2018 to 2019. Each control site represents an un-impacted ("natural") increase/decrease of throughput from 2018 to 2019 that is predominantly unaffected by the opening of the new Express Lane facilities. The pairing of sites is shown in Table 3.

Table 3. Pairing of Test and Control Sites

Test Site	Control Site	Paired Peak Hours
Chastain Road at I-575 NB	Shallow Ford Road at I-85 NB	PM (3-7 PM)
Chastain Road at I-575 SB	Moores Mill Road at I-75 SB and Buford Highway at I-285 WB*	AM (6-10 AM)
Hickory Grove Road at I-75 NB	University Avenue at I-75/I-85 SB	PM (3-7 PM)
Hickory Grove Road at I-75 SB	Buford Highway at I-285 EB	AM (6-10 AM)
Indian Trail/Lilburn Road at I-85 NB	Shallow Ford Road at I-85 NB	PM (3-7 PM)
Indian Trail/Lilburn Road at I-85 SB	Buford Highway at I-285 WB	AM (6-10 AM)
Old Peachtree Road at I-85 NB	Shallow Ford Road at I-85 NB	PM (3-7 PM)
Old Peachtree Road at I-85 SB	Buford Highway at I-285 EB	AM (6-10 AM)

* Chastain Road at I-575 SB was paired with two control sites (see discussions below).

Most of the test sites were paired to control sites with similar variability of speed profiles across the day time (6 AM to 7 PM). Chastain Road at I-575 NB was paired with Shallow Ford Road at I-85 NB (Figure 14), Indian Trail/Lilburn Road at I-85 NB was paired with Shallow Ford Road at I-85 NB (Figure 15), Indian Trail/Lilburn Road at I-85 SB was paired with Buford Highway at I-285 WB (Figure 16), and Old Peachtree Road at I-85 NB was paired with Shallow Ford Road at I-85 NB (Figure 17). The pairings of these sites indicate overall similarities of speed variability (in terms of when the peak occurs and the extent of speed decrease of peak hour) across all hours from morning (6 AM) to evening (7 PM). The small speed variability (flat speed curve) at Hickory Grove Road at I-75 NB (Figure 18) indicates relatively smaller demand variability (not large enough to cause significant speed drop), and a pairing based on only speed might not lead to a representative result given the insensitivity of speed variability. To further examine the variabilities of flow rates of each site, Hickory Grove Road at I-75 NB was paired with University Avenue at I-75/I-85 SB, based on the similar demand variances across time of day (Figure 19).

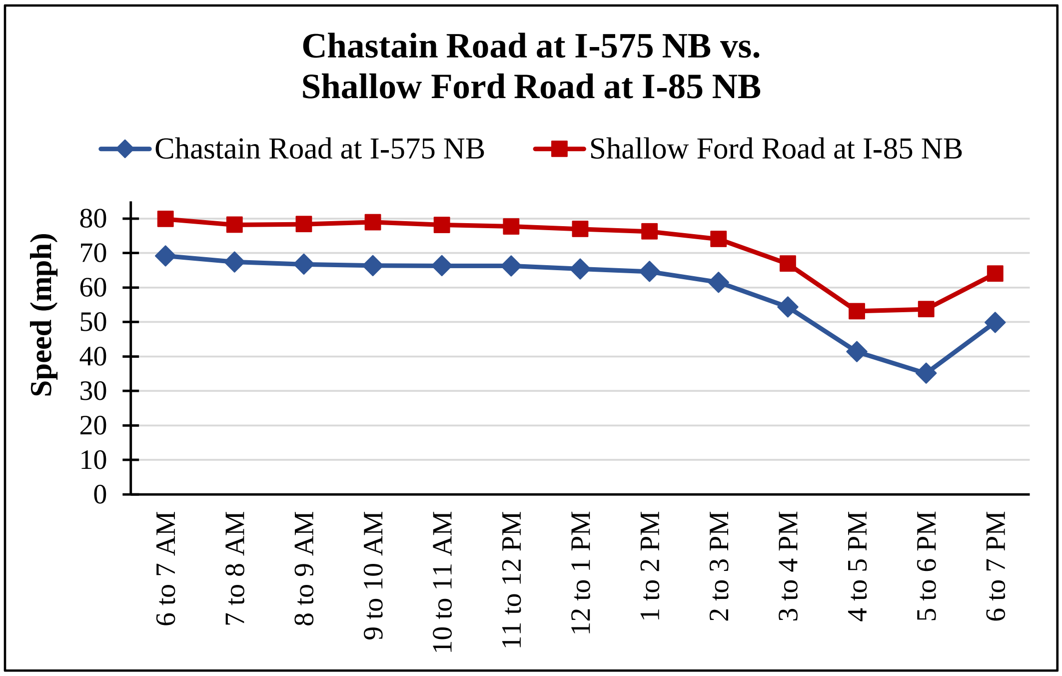


Figure 14. Speed Variability of Chastain Road at I-575 NB vs. Shallow Ford Road at I-85 NB

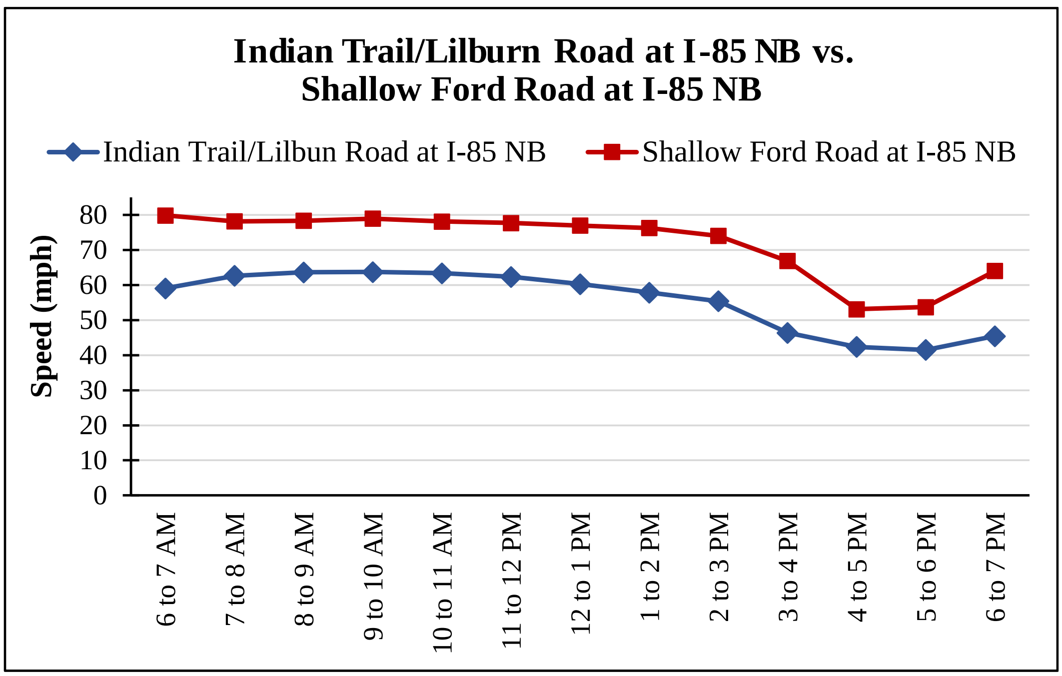


Figure 15. Speed Variability of Indian Trail/Lilburn Road at I-85 NB vs. Shallow Ford Road at I-85 NB

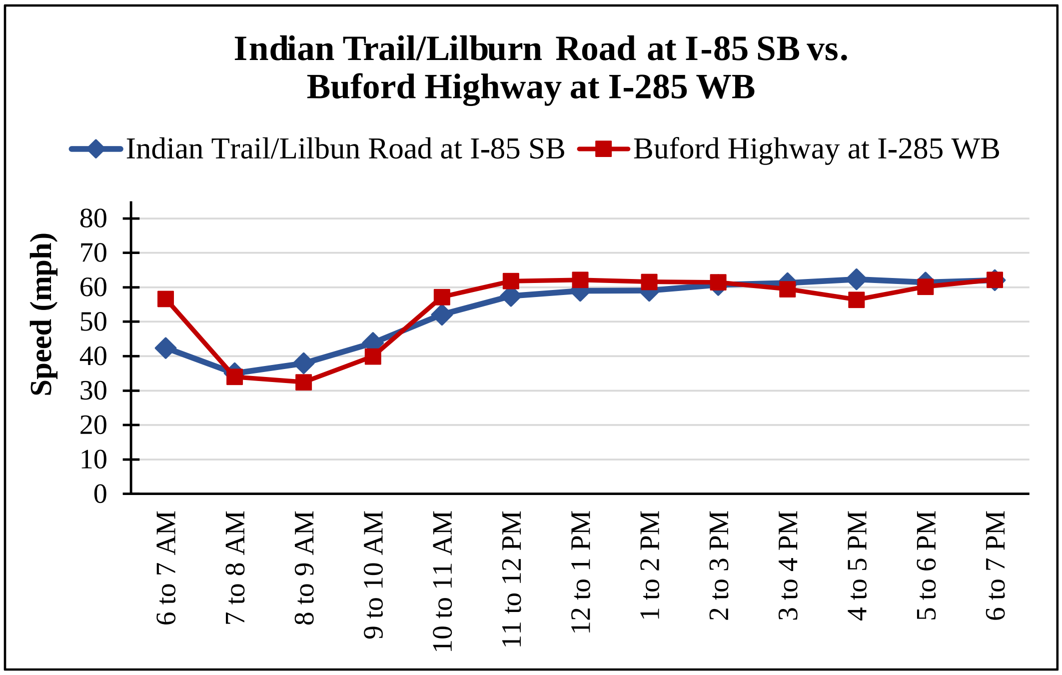


Figure 16. Speed Variability of Indian Trail/Lilburn Road at I-85 SB vs. Buford Highway at I-285 WB, Pre-Opening (2018)

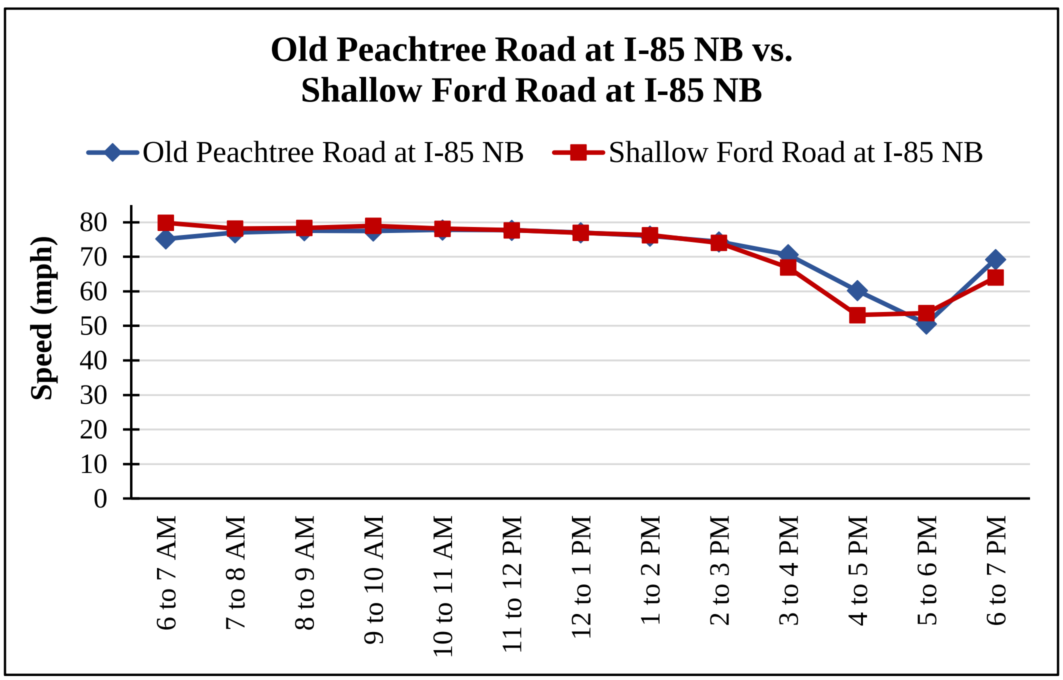


Figure 17. Speed Variability of Old Peachtree Road at I-85 NB vs. Shallow Ford Road at I-85 NB

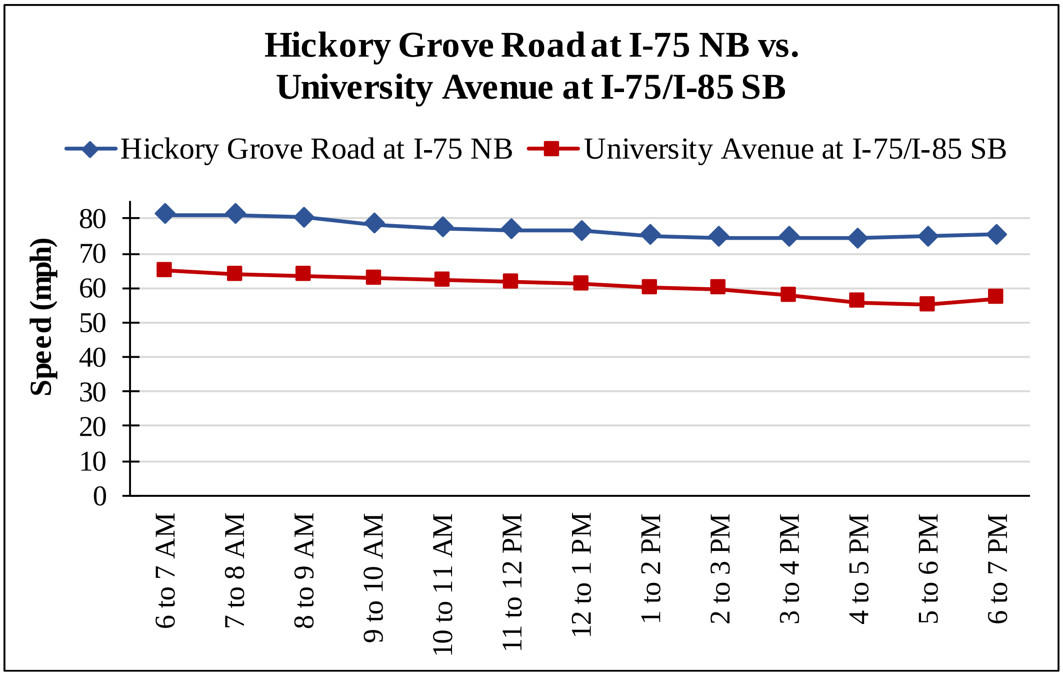


Figure 18. Speed Variability of Hickory Grove Road at I-75 NB vs. University Avenue at I-75/I-85 SB

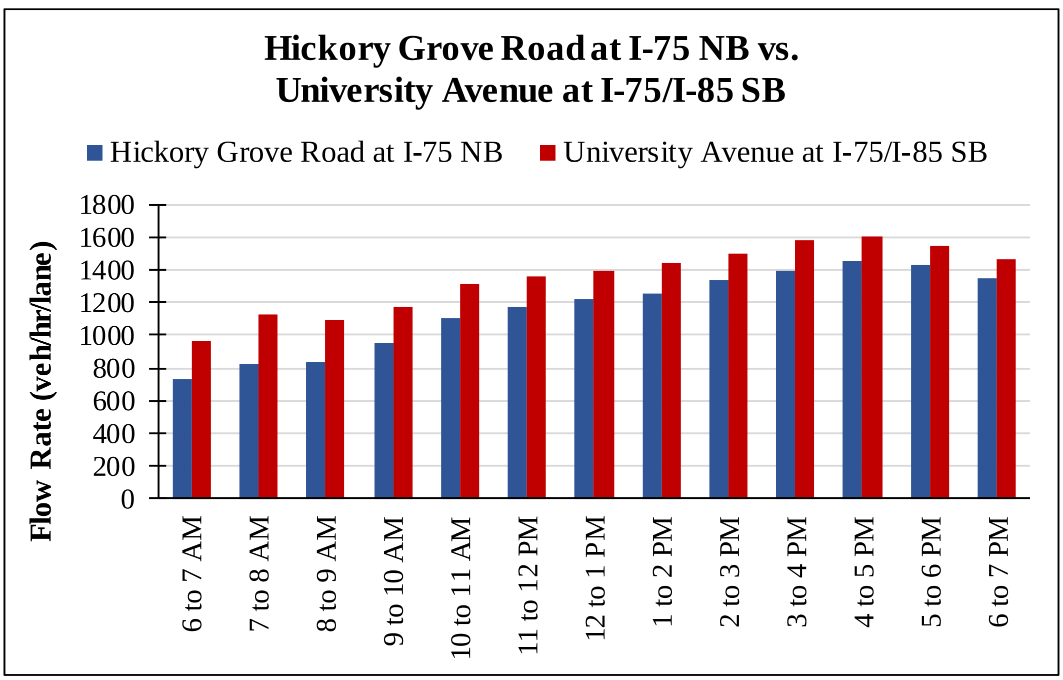


Figure 19. Flow Rate Variability of Hickory Grove Road at I-75 NB vs. University Avenue at I-75/I-85 SB

Similarly, speed variabilities at Hickory Grove Road at I-75 SB (Figure 20) and at Old Peachtree Road at I-85 SB (Figure 21) were also small. However, the team did not find any control site that resembles either of these test site in terms of the daytime demand (flow rate) variances. The team paired Hickory Grove Road at I-75 SB with Buford Highway at I-285 EB (Figure 22), and Old Peachtree Road at I-85 SB with Buford Highway at I-285 EB (Figure 23), based on peak hour only (in this case, it is morning peak for both of the two inbound sites), and these should still be valid pairings, as the before-and-after comparison of emissions only focused on peak hours. This study focuses on the morning and evening peak hours when inbound traffic occurs, but not all the control sites were paired based on their inbound traffic variabilities.

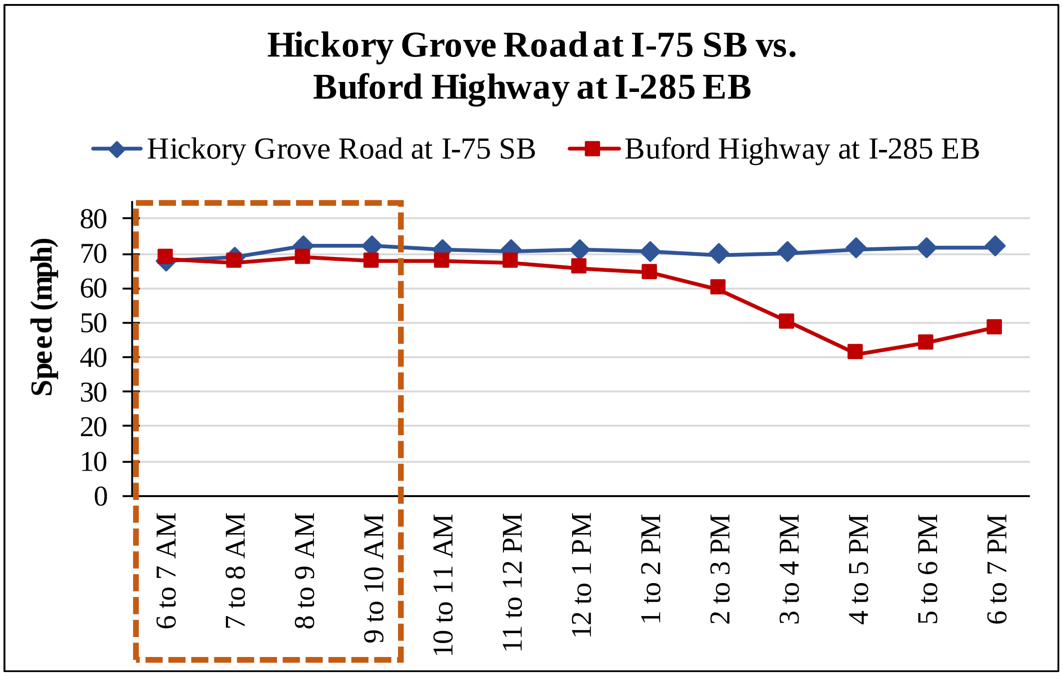


Figure 20. Speed Variability of Hickory Grove Road at I-75 SB vs. Buford Highway at I-285 EB

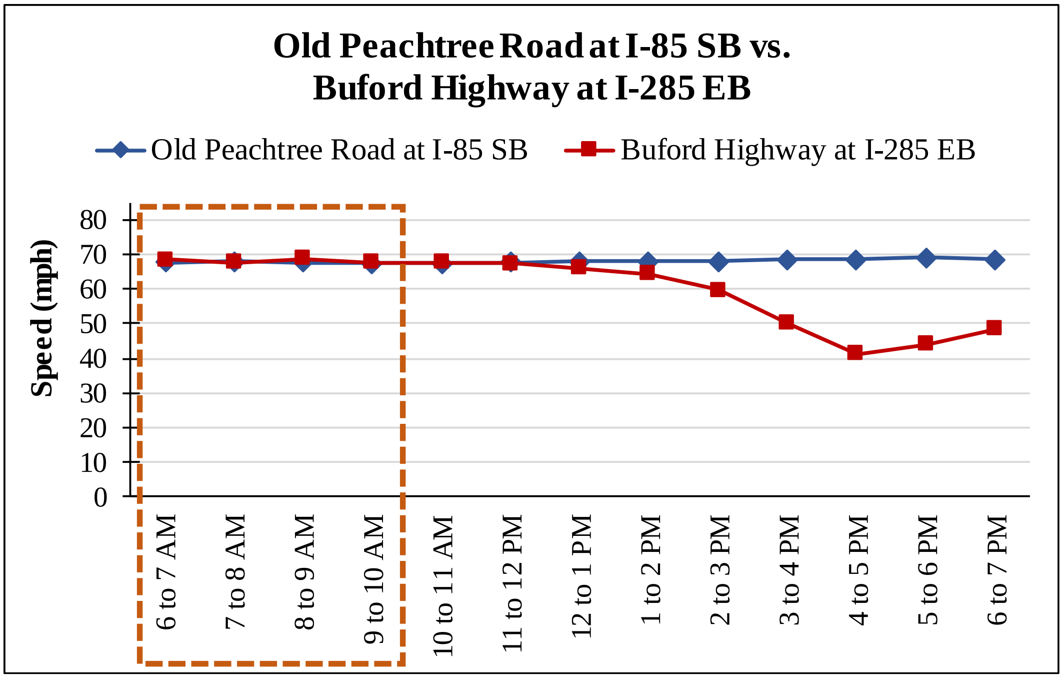


Figure 21. Speed Variability of Old Peachtree Road at I-85 SB vs. Buford Highway at I-285 EB

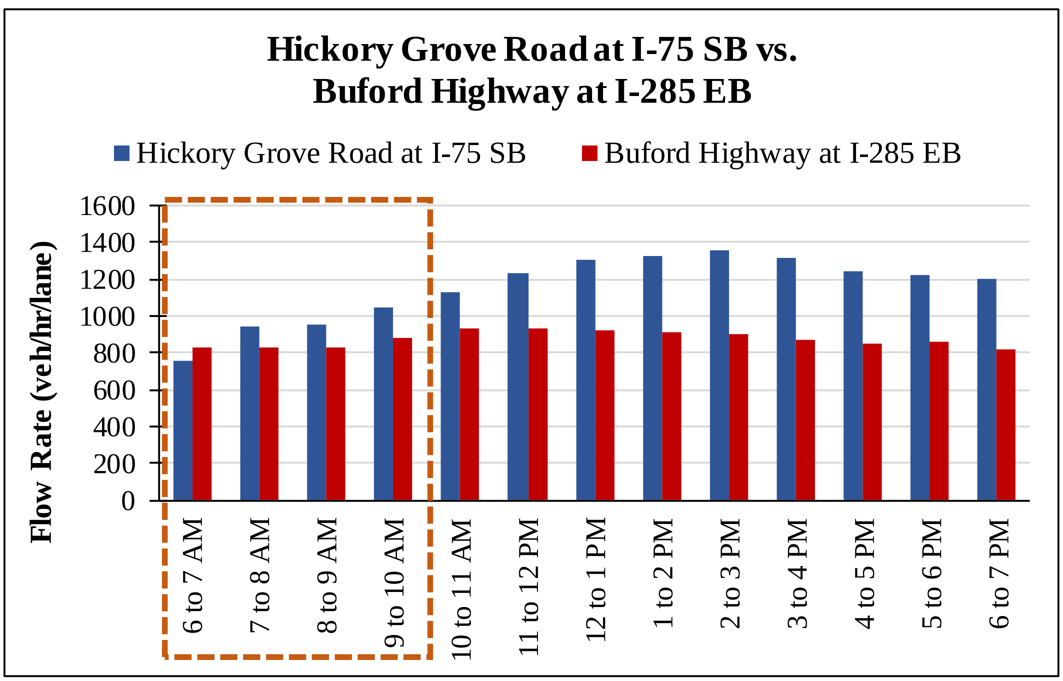


Figure 22. Flow Rate Variability of Hickory Grove Road at I-75 SB vs. Buford Highway at I-285 EB

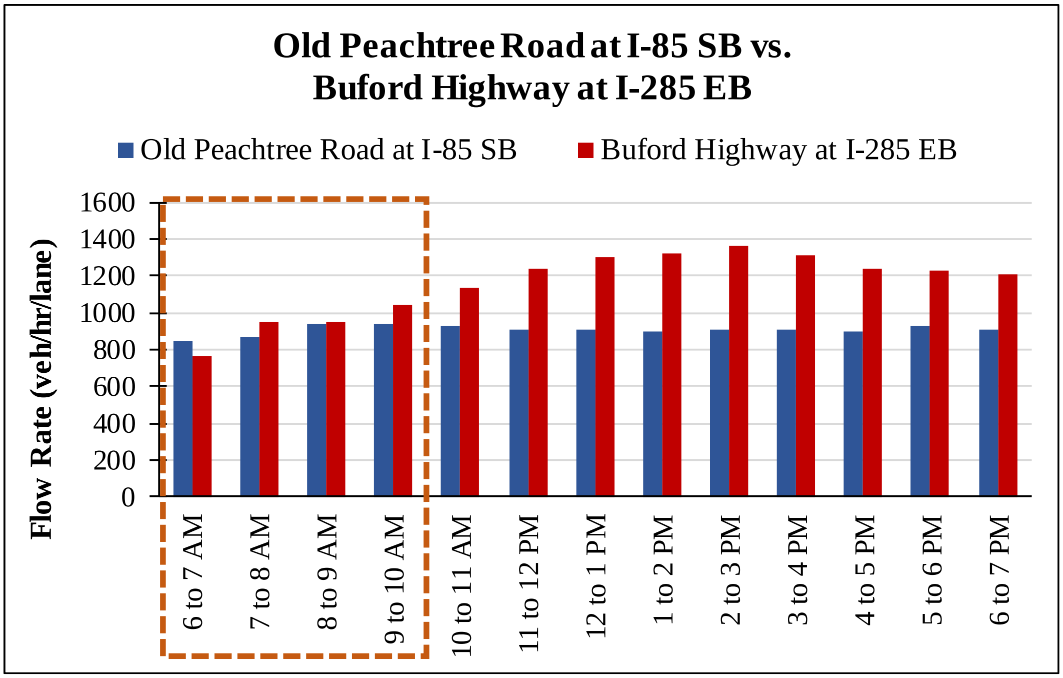


Figure 23. Flow Rate Variability of Old Peachtree Road at I-85 SB vs. Buford Highway at I-285 EB

After examining all control sites, the team did not find a control site that could be properly paired with Chastain Road at I-575 SB for similar morning peak speed variabilities. The two potential matches were Moores Mill Road at I-75 SB (Figure 24 and Figure 26) and Buford Highway at I-285 WB (Figure 25 and Figure 27), both of which saw speed decreases during morning peak. Given that the morning peak speed decrease at Buford Highway at I-285 WB are larger than Chastain Road at I-575 SB (busier in the morning), the team assumes a smaller constant change ("natural" increase) if Buford Highway is selected (given it is already busy). That is, using Buford Highway at I-285 WB is likely to lead to a more conservative estimate. However, Moores Mill Road is on the downstream of Chastain Road (I-575 merges to I-75 for inbound traffic), and could be carrying a similar group of travelers with Chastain Road at I-575. The team presented the larger results of pairing Moores Mill Road and Buford Highway (conservative estimate), but these results must be considered somewhat uncertain. A larger pool of potential control sites would be helpful for future studies, but it may be that it will not be possible to identify adequate control sites for every location.

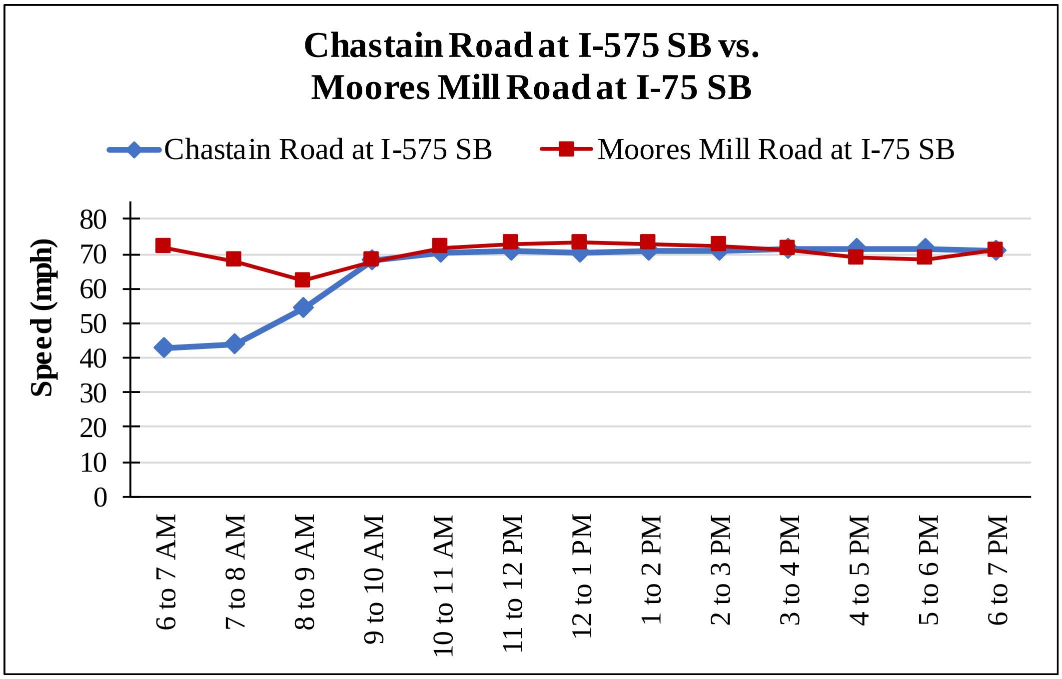


Figure 24. Chastain Road at I-575 SB vs. Moores Mill Road at I-75 SB

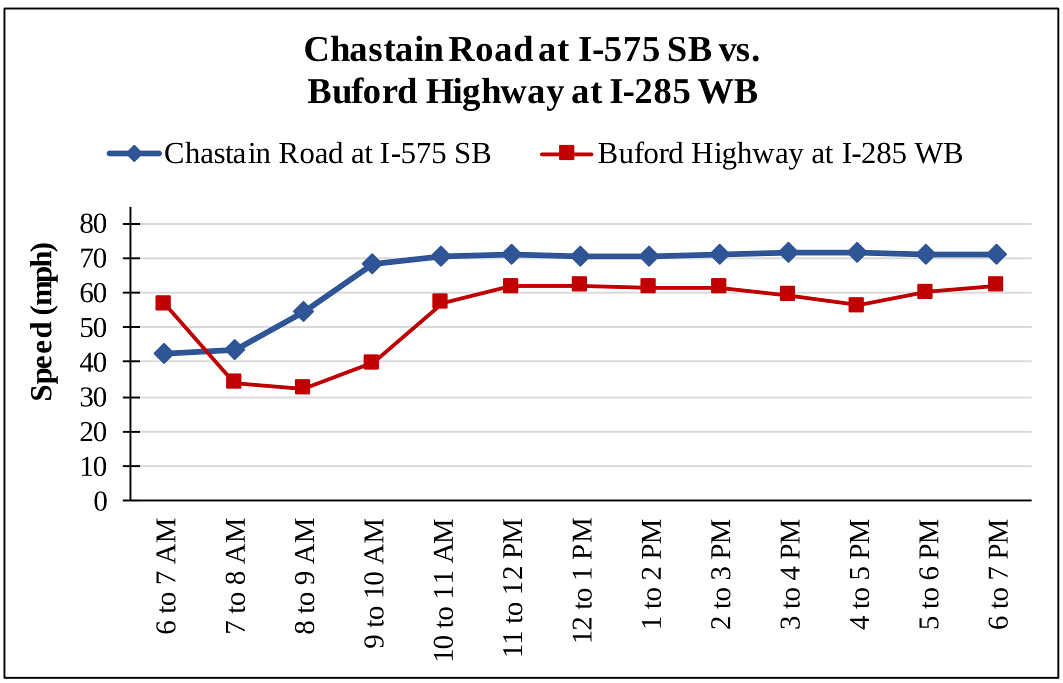


Figure 25. Chastain Road at I-575 SB vs. Buford Highway at I-285 WB

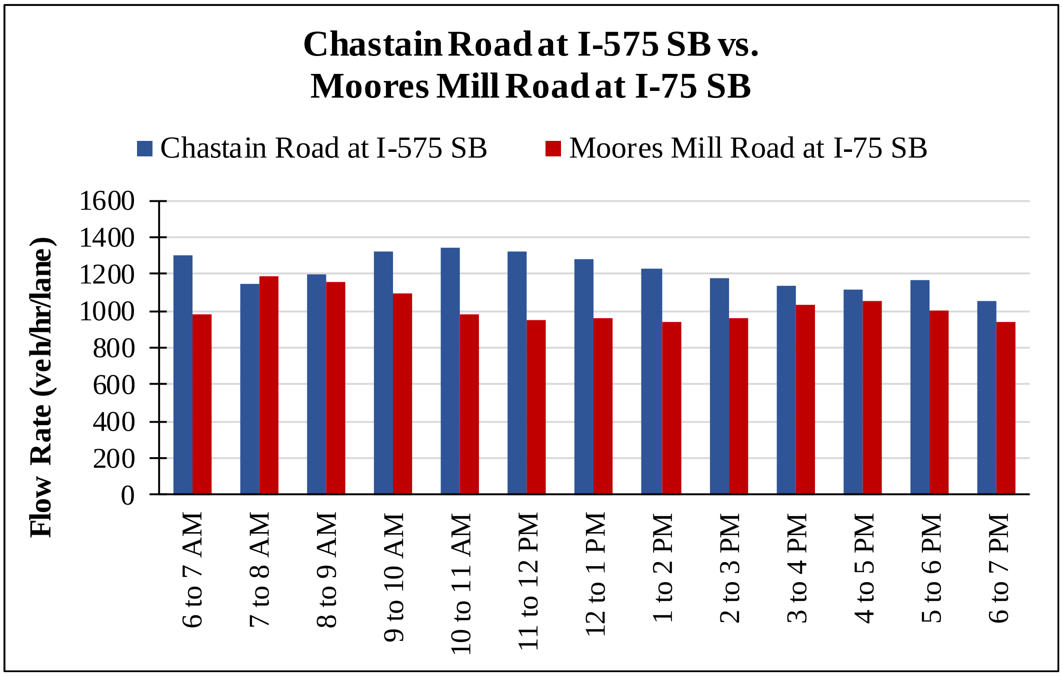


Figure 26. Chastain Road at I-575 SB vs. Moores Mill Road at I-75 SB

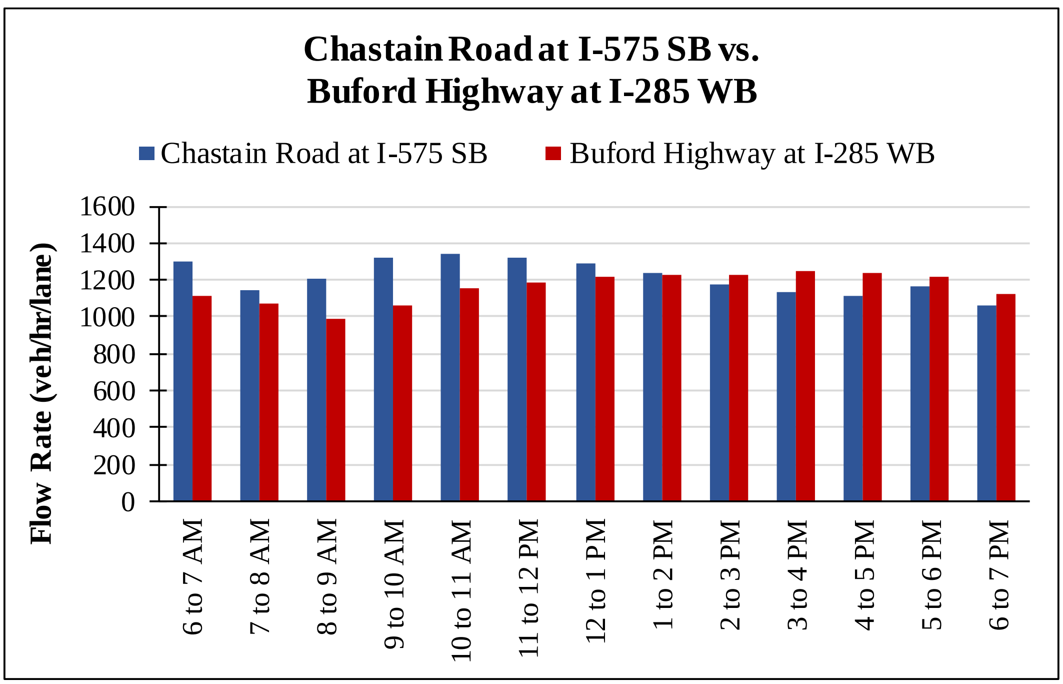


Figure 27. Chastain Road at I-575 SB vs. Buford Highway at I-285 WB

For any test site, its "natural" change in vehicle throughput is represented by the net change at the paired control site, as shown in Equation (1), and the actual throughput impact of the opening of the facilities were derived after excluding the "natural" changes, as shown in Equation (2).

$$THChange_{control} = \frac{THC_{after} - THC_{before}}{THC_{before}} \times 100\% \quad (1)$$

$$THImpact_{test} = \frac{THT_{after} - THT_{before} \times Change_{control}}{THT_{before} \times Change_{control}} \times 100\% \quad (2)$$

Where $THImpact_{test}$ is the impact on throughput at a test site due to the opening, $THChange_{control}$ is the "natural" change based on the control site, THT_{before} is the throughput at the test site before the opening, THT_{after} is the throughput at the test site after the opening, THC_{before} is the throughput at the control site before the opening, and THC_{after} is the throughput at the paired control site after opening.

1.2 Emissions Modeling: MOVES-Matrix

Link-by-link emission rates for the County fleet composition, on-road vehicle speed, and environmental conditions were extracted from MOVES-Matrix, which generates exactly the same results as running the USEPA MOVES 2014b model for the analysis (Kim et al., 2020a; Liu et al., 2019, 2017). The fleet composition (source type distribution) for each link and the paired vehicle age distributions were derived from each County's (Cobb County, Cherokee County, and Bartow County) on-road vehicle mix used in the ARC's regional conformity plan (ARC, 2015) and in previous research by the team (Xu et al., 2018). The hourly AERMET meteorological profiles were provided by the GA EPD (24 hours × 365 days of the year for 2019); used to configure the meteorology input to MOVES-Matrix to obtain applicable emission rates (Georgia EPD, 2021). The resultant emissions rates from MOVES-Matrix were assigned to each ABM link and to each AERMOD source accordingly, which were converted to mass flux input emissions rates for use with AERMOD polygon sources.

The emissions rates of CO were estimated using MOVES-Matrix based on on-road traffic volumes, speeds, and fleet compositions. MOVES-Matrix was developed by Georgia Tech to facilitate rapid applications of emissions modeling with the same output with the regulatory model of MOVES (Guensler et al., 2016). By running MOVES about thirty thousand times for a region (i.e., areas that employ the same fuel specification and inspection and maintenance programs), across all combinations of input variables that affect emission rates, a multi-dimensional emission rate matrix of 90 billion energy and emission rates is generated. Users can query the emission rates directly from the matrix and thus improve run time efficiency (Guensler et al., 2016); performing a matrix query is about 200x faster than a MOVES run.

MOVES-Matrix also supports analyses of engine starts, truck hoteling, evaporative sources, brake/tire wear (X. Xu et al., 2017), and can be used to model the emissions from individual vehicles (Guensler et al., 2017). MOVES-Matrix can be easily coupled with vehicle activity analysis (Li et al., 2017, 2016; Y. Xu et al., 2017) by importing second-by-second vehicle operations. MOVES-Matrix can also be applied to a variety of transportation models, such as travel demand models (Xu et al., 2018), and microscopic traffic simulation models (Xu et al., 2016), or applications of emissions modeling that require high-efficient model performance such as sensitivity assessment (Lu et al., 2021b, 2020).

MOVES-Matrix is highly-desirable for regional-scale dispersion analysis (Kim et al., 2020b; Lu et al., 2021a), with high-performance to deal with links from large-scale networks, variations in meteorology, and traffic operation input, and with its user-friendly nature to minimize potential human error in running MOVES (especially when analyses require inputs for large numbers of links and/or when modeled conditions on these links change over time).

MOVES-Matrix provides a massive look-up table for each modeling region, and for the Atlanta metro area, MOVES-Matrix contains sub-matrices based on combinations of calendar year, season (Spring/Fall, Summer, Winter fuel season), temperature (0º-110º F with 1º F-bin interval, 111 bins in total for Atlanta), and relative humidity (0%-100% with 5%-bin interval, 21 bins in total for Atlanta). Meteorological data from AERMET are rounded to the appropriate temperature and humidity values used in sub-matrices for each MOVES-Matrix run.

1.2.1 Input to MOVES-Matrix

The daytime emissions (from 6 AM to 8 PM), by hour for both before- (2018) and after- (2019) the opening of the Express Lane facilities, were modeled using MOVES-Matrix. The hour-by-hour speed and traffic volumes from the NaviGAtor data were entered into MOVES-Matrix to provide the input of traffic operations, and the freeway GP lanes and Express Lanes were modeled separately per site.

The input fleet composition to emissions modeling were extracted from the previous research by the team (X. Xu et al. 2018) to provide source type distributions and age distributions to MOVES-Matrix. In support of the regional conformity plan, the 20-county nonattainment area was divided into 13-county vs. 7-county areas, where separate fleet compositions were applied for each area in MOVES modeling (ARC 2015). The distribution of counties is shown in Table 4. Cobb County and Cherokee County belong to the 13-county area, and Bartow County belongs to the 7-county area. Four sets of fleet compositions were used in support of the regional conformity plan for the year of 2017, 2024, 2030, and 2040, respectively. The fleet composition calendar year 2017 was used in this research (source type distribution shown in Table 5) for both calendar years of 2018 and 2019, and the corresponding fleet composition for each modeled site (test and control sites) was allocated based upon county group membership. Future analyses can incorporate observed fleet composition data (source type and age distributions) into the modeling process using data extracted from video profiles and license plate data collection (i.e., vehicle make, model and model year information in the vehicle registration database).

Table 4. County Division of Regional Conformity Plan (ARC 2015)

County Name	Area
Fulton	13-county
DeKalb	13-county
Cobb	13-county
Gwinnett	13-county
Rockdale	13-county
Henry	13-county
Clayton	13-county
Fayette	13-county
Douglas	13-county
Cherokee	13-county
Coweta	13-county
Forsyth	13-county
Paulding	13-county
Bartow	7-county
Carroll	7-county
Spalding	7-county
Newton	7-county
Walton	7-county
Barrow	7-county
Hall	7-county

Table 5. Input Source Type Distributions (ARC 2015)

Source Type #	Distribution in 13-County Area	Distribution in 7-County Area
11	2.11%	2.84%
21	53.91%	47.22%
31	31.00%	35.32%
32	10.12%	11.55%
41	0.03%	0.01%
42	0.02%	0.01%
43	0.33%	0.32%
51	0.04%	0.03%
52	1.25%	1.23%
53	0.09%	0.09%
54	0.13%	0.15%
61	0.62%	0.53%
62	0.35%	0.70%

For each hour in calendar years of 2018 and 2019, corresponding sub-matrices within MOVES-Matrix were extracted for use in project-level analyses to provide the energy use rates and emission rates for CO, NO_x, and $PM_{2.5}$. Hourly input data sets were used to pull hourly emission rate data from MOVES-Matrix for each analysis, as described in a previous section:

- Speed and volumes were derived from the ARC's ABM2020
- Driving cycles were embedded in MOVES for average speed and facility type
- Source type distributions and vehicle age distributions by source type were taken from the regional conformity analysis
- Meteorology data were contained in AERMET profiles used in regional conformity analyses provided by GA EPD

The emission rate outputs for Chastain Road at I-575 were compiled to provide the link-by-link emission rate inputs for AERMOD dispersion modeling on PACE supercomputing cluster.

1.2.2 Accounting for the Impact of the Express Lane Openings

Similar to the throughput changes, the net changes in emission rates at a test site can result from factors external to the Express Lane Opening, such as technology improvements of vehicle engines in the fleet over time and region-wide changes in operating conditions, which influence the emission rates. The team excluded the "natural" changes in emissions based on the same test-control site pairs. For any test site, its "natural" change in energy use or emissions is represented by the net change at the paired control site, as shown in Equation (3), and the actual impact of the facility opening is derived after excluding the "natural" changes, as shown in Equation (4). The changes in emissions are not necessarily in proportion to vehicle throughput (traffic volume) due to the non-linear relationship between emission rates and speed, and a sensitivity analysis is provided in the results section of this report.

$$EChange_{control} = \frac{EC_{after} - EC_{before}}{EC_{before}} \times 100\% \tag{3}$$

$$EImpact_{test} = \frac{ET_{after} - ET_{before} \times EChange_{control}}{ET_{before} \times EChange_{control}} \times 100\% \tag{4}$$

Where $EImpact_{test}$ is the impact on emissions at a test site due to the opening, $EChange_{control}$ is the "natural" change based on the control site, ET_{before} is the emissions at the test site before the opening, ET_{after} is the emissions at the test site after the opening, EC_{before} is the emissions at the control site before the opening, and EC_{after} is the emissions at the paired control site after opening.

1.3 Dispersion Modeling: AERMOD

The team performed dispersion modeling using the USEPA's latest version of AERMOD (V21121) with AREAPOLY source types representing the transportation links (allows users to define an irregularly shaped polygon with up to 20 vertices by entering the coordinates of each vertex). The AREAPOLY sources were created based on the ABM network for Chastain Road at I-

575 for this case study, and the GP freeway lanes (NB and SB) and the Express Lanes were modeled separately. This corridor and subarea have been the subject of extensive emissions and dispersion modeling efforts by the Georgia Tech research team (Lu, et al., 2023; Guensler, et al. 2021c; Kim, et al. 2020) and encompasses a variety of projects of potential policy concern, including major intersections, managed lanes, and direct access ramps.

The link-specific emission rates for the County fleet composition, vehicle speed, and environmental conditions are pulled from MOVES-Matrix for MOVES 2014b, which produces the exact same results as running the USEPA MOVES 2014b model for every analysis (Kim, et al., 2020; Liu, et al., 2019; Liu, et al., 2017). Even though the pre-processed MOVES model lookup matrix contains more than 90 billion cells, emission rates applicable to any corridor or transportation link can be queried 200 times faster than performing any individual MOVES model run (and there is no need to develop any MOVES input files, as the MOVES model was already been run for every combination of input variable to develop the matrices).

The fleet composition (source type distribution) for each link was derived from each County's (Cobb County, Cherokee County, and Bartow County) on-road vehicle mix used in the ARC's regional conformity planning (ARC, 2015) and in previous regional research by the team (Xu, et al. 2018). The hourly AERMET meteorological profiles were provided by the GA EPD (24 hours × 365 days of the year for 2019); used to configure the meteorology input to MOVES-Matrix for MOVES 2014b to obtain applicable emission rates. The resultant emissions rates from MOVES-Matrix were assigned to each ABM link, which were converted to the input emissions rates of AERMOD sources. A detailed description of the methodology and data with respect to generation and assignment of these emissions rates are provided later in the report.

AERMOD allows users to specify receptor locations. The receptors define the physical locations in x, y, z space for which pollutant concentrations will be predicted for every hour in the simulated year. Receptors allow users to assess pollutant concentration levels relative to nearby locations of concern (e.g., near schools or residential areas where individuals are likely to be exposed to pollutant concentrations for extended periods) and to identify localized areas of high concentration. Assessment of receptor concentrations allows modelers to identify regions that may exceed NAAQS. The computing resources available for this project allowed the research team to assess as many receptors as desired, so a variety of receptor patterns were used in this study, including standard receptor grids and variable receptor grids.

Standard grids with 20-meter spacing between receptors were used in this study. Receptor grids provide a simple approach that requires minimal forethought, but is computationally inefficient because many of the receptors are placed so far from the roadway that pollutant concentrations are not significant and contribute little information. However, given the small number of roadway links, there is no need to adopt further optimization by filtering source-receptor pairs, as described in previous model assessments (Guensler, et al., 2021c).

2. Results and Discussion

This chapter presents and discusses the results of the net change percentages and the difference-in-difference assessment (impacts of the openings). In this study, all comparisons are presented as percentage change compared to the baseline of 2018 (pre-pandemic), and the percentages are rounded to one decimal place (see detailed tables in Appendix A).

It is worth noting that the scope of the study covers the test and control sites, but the impact of the Express Lanes likely extends beyond these stations. The significant decrease in congestion on the I-75/I-575 NWC, due to capacity expansion and bottleneck relief on the Interstate, likely attracted travels from other facilities; hence, some of the noted increase in vehicle throughput, energy use, and emissions are likely compensated by decreases on other corridors. Plus, the changes in operating conditions also likely reduced the energy use and emission rates per vehicle-mile of travel on the NWC and congested corridors from which the traffic was attracted.

2.1 Vehicle Throughput Changes

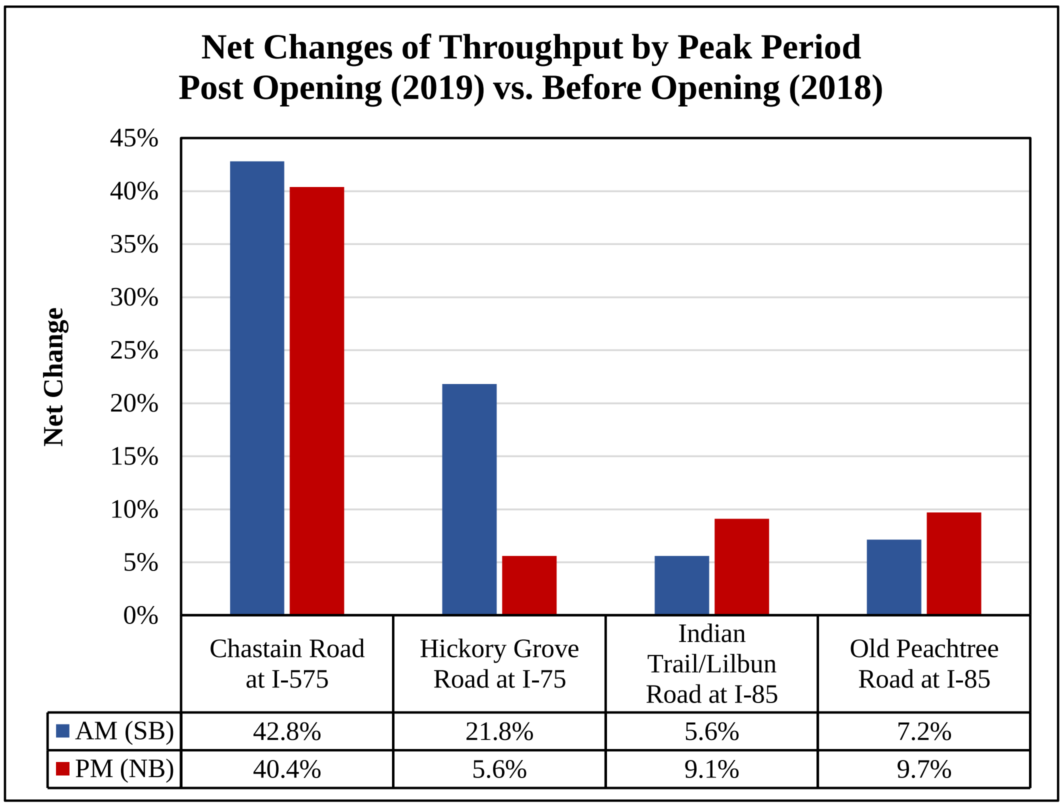
This section presents the vehicle throughput at the test sites for pre- and post- the openings of the Express Lanes, with the net changes and the impact (intervention effect) as percentages. Only morning (6 to 10 AM) and evening (3 to 7 PM) peak hours are analyzed for the throughput and emission changes, but the average speed changes are presented for all day time hours.

2.1.1 Net Changes in Vehicle Throughput

The percent change in vehicle throughput and person throughput of all sites are presented in Figure 28 and in Table 6. Throughput increases are observed at all sites for both morning and evening peak periods, which is anticipated given the natural growth of volume and given the congestion relief provided by the opening of the Express Lanes. Increases in vehicle throughput of more than 40% were found in both the morning and evening peak periods at Chastain Road at I-575, and an increase of more than 20% is observed at Hickory Grove Road at I-75 SB for the morning peak. The increases at I-575 are very large, with a large share contributed by the traffic volume on the Express Lane (as indicated in Table 6, the throughput increase of GP lanes only increased by about 10%). The increase in capacity significantly reduced corridor congestion (increasing speeds by about 20 mph during the peak of the morning peak), which likely attracted commuters from other facilities (e.g., local arterial commute paths), may have attracted users from a larger geographic area, as indicated by the Volume II report (Guensler et al. 2021), or may have attracted previous users who may have diverted to other routes during facility construction back to the facility. The team performed a supplemental QA/QC process on the volume profiles at Chastain Road at I-575, as describe in the next sub-section.

The increases at other sites are no larger than 10%, which is not surprising to the team. The evening peak increase at I-85 corridor is larger than its morning peak increase (approximately 9% for evening peak vs. 5% to 7% for morning peak), and this could indicate that the openings have larger impact on evening peak traffic. The Express Lane at Old Peachtree Road contributed to a much larger increase in morning peak (more than 23.9%) in the than evening peak (0.1%). This may have resulted from differences in trip purposes for morning vs. evening peaks (morning traffic is composed of mostly commute trips, while evening trips consists of more recreational trip purposes such as shopping, dining, etc.), given that the morning peak travel speed (see Figure 21) is close to free-flow speed and already faster than that of the evening peak (see Figure 16). Travelers with recreational purposes are much less sensitive than commuters, and are less likely to pay (or to carpool) for a shorter and more reliable travel time. To assess these results in more detail, a follow-up study on commuting decisions as part of the next customer service survey is recommended.

Because travel speeds do not change in proportion to changes in flow rate (see Figure 12), and because emission rates are also a non-linear function of operating speeds, an increase in vehicle throughput does not lead to proportional changes in energy use, emissions, and pollutant concentrations, as will be discussed in the next section.



	Chastain Road at I-575	Hickory Grove Road at I-75	Indian Trail/Lilbun Road at I-85	Old Peachtree Road at I-85
AM (SB)	42.8%	21.8%	5.6%	7.2%
PM (NB)	40.4%	5.6%	9.1%	9.7%

Figure 28. Net Change Percentage of Vehicle Throughput by Site

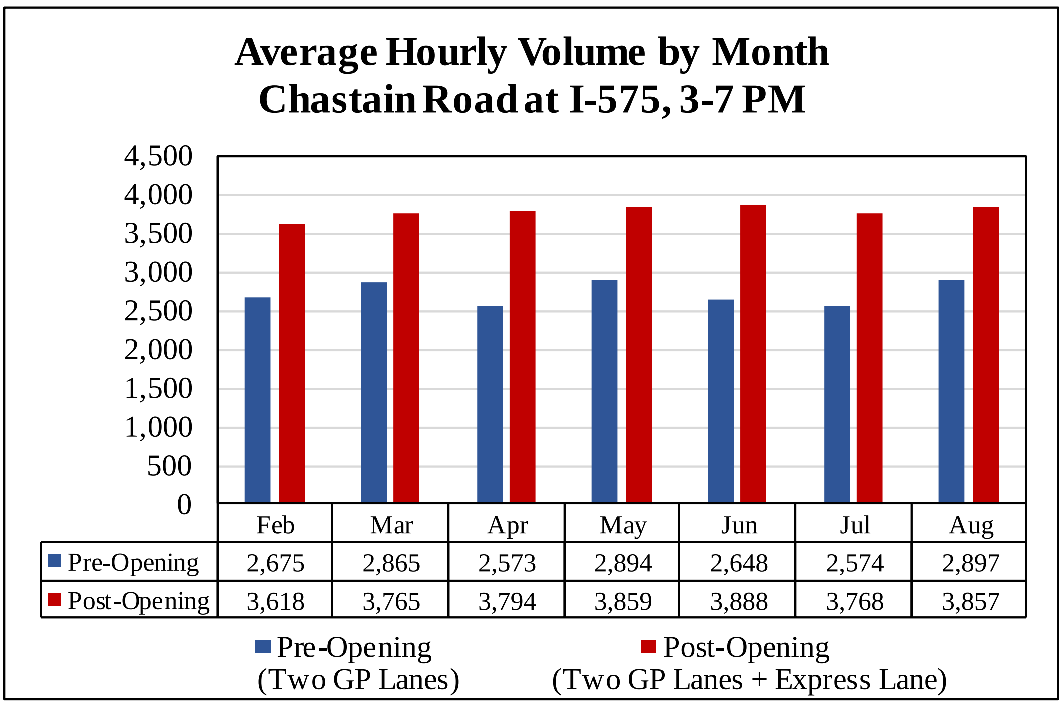
Table 6. Net Change Percentage of Vehicle Throughput by Site and Lane Type

AM/PM	Site	Lane Type	Percent Change in Vehicle Throughput
AM	Chastain Road at I-575	All	42.8%
AM	Chastain Road at I-575	GP	12.1%
AM	Chastain Road at I-575	ML	N/A
AM	Hickory Grove Road at I-75	All	21.8%
AM	Hickory Grove Road at I-75	GP	8.5%
AM	Hickory Grove Road at I-75	ML	N/A
AM	Indian Trail/Lilburn Road at I-85	All	5.6%
AM	Indian Trail/Lilburn Road at I-85	GP	5.9%
AM	Indian Trail/Lilburn Road at I-85	ML	3.9%
AM	Old Peachtree Road at I-85	All	7.2%
AM	Old Peachtree Road at I-85	GP	5.9%
AM	Old Peachtree Road at I-85	ML	23.9%
PM	Chastain Road at I-575	All	40.4%
PM	Chastain Road at I-575	GP	-0.8%
PM	Chastain Road at I-575	ML	N/A
PM	Hickory Grove Road at I-75	All	5.6%
PM	Hickory Grove Road at I-75	GP	-3.4%
PM	Hickory Grove Road at I-75	ML	N/A
PM	Indian Trail/Lilburn Road at I-85	All	9.1%
PM	Indian Trail/Lilburn Road at I-85	GP	10.5%
PM	Indian Trail/Lilburn Road at I-85	ML	2.1%
PM	Old Peachtree Road at I-85	All	9.7%
PM	Old Peachtree Road at I-85	GP	11.4%
PM	Old Peachtree Road at I-85	ML	0.1%

2.1.2 Verification of Throughput Changes at I-75/I-575 NWC

The research team observed a large increase in vehicle volumes at Chastain Road at I-575 for both 6-10 AM (38.8%) and 3-7 PM (35.6%) and at Hickory Grove Road at I-75 for 6-10 AM (21.8%). The large increase was initially suspected of being a data issue, perhaps associated with a NaviGAtor Express Lane device mismatch, poor data quality, etc. However, it also might have meant that the post-opening scenario resulted in a large portion of increase in commute travel demand on I-75/I-575. It was important to investigate the source of the large throughput increase, and to conduct a supplemental QA/QC process to make sure the input data were valid. This section describes the assessment efforts and the conclusion that the traffic volumes and person throughput did indeed increase.

Figure 29 (Chastain Road at I-575, AM peak), Figure 30 (Chastain Road at I-575, PM peak), and Figure 31 (Hickory Grove Road at I-75, AM peak) illustrate the large increase in average hourly vehicle volume (i.e., input to the vehicle throughput assessment) on the NWC, from the GA NaviGAtor database. The hourly volume for Chastain Road at I-575 increased by approximately 41.2% in the morning peak, and 38.8% in the evening peak, and the traffic volumes at Hickory Grove Road at I-75 increased by approximately 20.5%.



	Feb	Mar	Apr	May	Jun	Jul	Aug
Pre-Opening	2,675	2,865	2,573	2,894	2,648	2,574	2,897
Post-Opening	3,618	3,765	3,794	3,859	3,888	3,768	3,857

Figure 29. Hourly Traffic Volume (Tuesday, Wednesday and Thursday) by Month, Chastain Road at I-575, AM Peak (6-10 AM), All Lanes

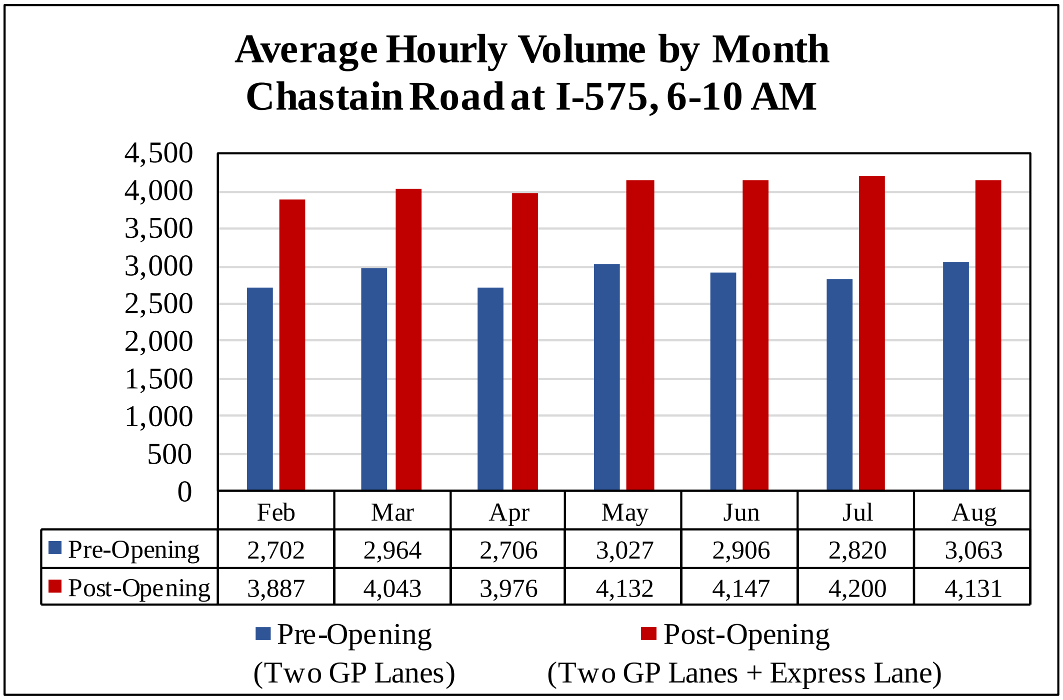


Figure 30. Hourly Traffic Volume (Tuesday, Wednesday and Thursday) by Month, Chastain Road at I-575, PM Peak (3-7 PM), All Lanes

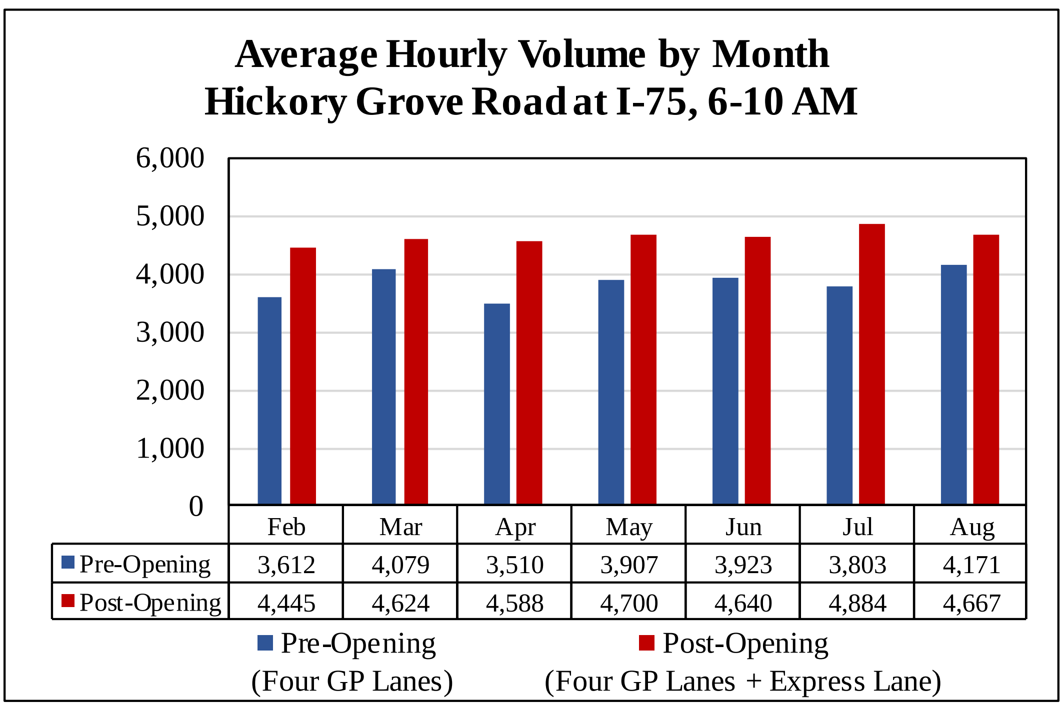


Figure 31. Hourly Traffic Volume (Tuesday, Wednesday and Thursday) by Month, Hickory Grove Road at I-75, AM Peak (6-10 AM), All Lanes

GDOT constructed additional VDS devices to accommodate the facility change, separated from the existing devices that capture the flow of the GP lanes, and these new devices for the Express Lane were used to further verify the change in traffic operations. The following steps were implemented to validate the volume profiles as input to the throughput assessment of I-75/I-575 NWC.

1. Review of QA/QC and Imputation Methodology

All the 20-second speed and volume profiles were thoroughly reviewed to make sure they were processed following the QA/QC procedure described in Section 1.1.1. The imputation was also checked to make sure it strictly followed the proposed methodology. The time-series of speed and volumes at 5-minute bins were also reviewed for potential extreme values. The team verified that all steps were conducted based on the designed methodology and no error was found in this step.

2. Review of Lane-by-Lane Average Flow Rate by Month

The flow rates data (hourly volume per lane) of Chastain Road at I-575 were reviewed on a lane-by-lane basis for the year of 2018 (pre-opening) and 2019 (post-opening). From a perspective of traffic engineering and traffic flow theory, flow rates of a specific lane usually fall into a common range. Also, the managed lane usually has a slightly lower capacity than the adjacent GP lanes. Figure 32 and Figure 33 present the monthly average flow for AM peaks (6-10 AM) and PM peaks (3-7 PM), respectively, in vehicle/hour/lane.

With respect to the average flow rate for the Express Lane (Lane #1), the managed lanes in both directions were major contributors to the large increase in corridor traffic volumes. The average monthly flow rate of the Express Lane ranges from 802 to 952 vehicles/hour/lane for Southbound (AM peak), and from 1,049 to 1,193 vehicles/hour/lane for Northbound (PM peak). As noted above, Express Lane volumes and speeds were measured by independent NaviGAtor devices that are separated from the GP lanes. While concerns might arise regarding the possibility of the managed lane devices over-counting traffic (e.g., poor calibration, the absence of heavy-duty vehicles, or using inappropriate Express-Lane devices to pair with GP-lane devices), the average flow rates of the Express Lane are still lower than those of the GP lanes. The team performed a further validation of the Express Lane volume based on manual vehicle counts and did not identify any bias or error in the volumes of the Express Lane (presented later in this section).

The second finding lies in the significant volume increase of Lane #2 (the inside GP lane). Although the average flow rate after the increase is still considered within a reasonable range (approximately 1,900 vehicles/hour/lane). The increase might have resulted from a re-calibration of the VDS device, but there were no obvious signs that this would be likely. It seems more likely that traffic diverted from other routes or the shoulder of the peak into the primary morning peak once congestion declined.

To address these concerns, the team then implemented a cross validation of nearby devices (one parallel I-75 station and upstream and downstream stations of the same corridor), followed by a manual count of traffic volumes from the field recorded video profiles. Hence, the team concluded that the observational data were valid and that corridor vehicle throughput did significantly increase.

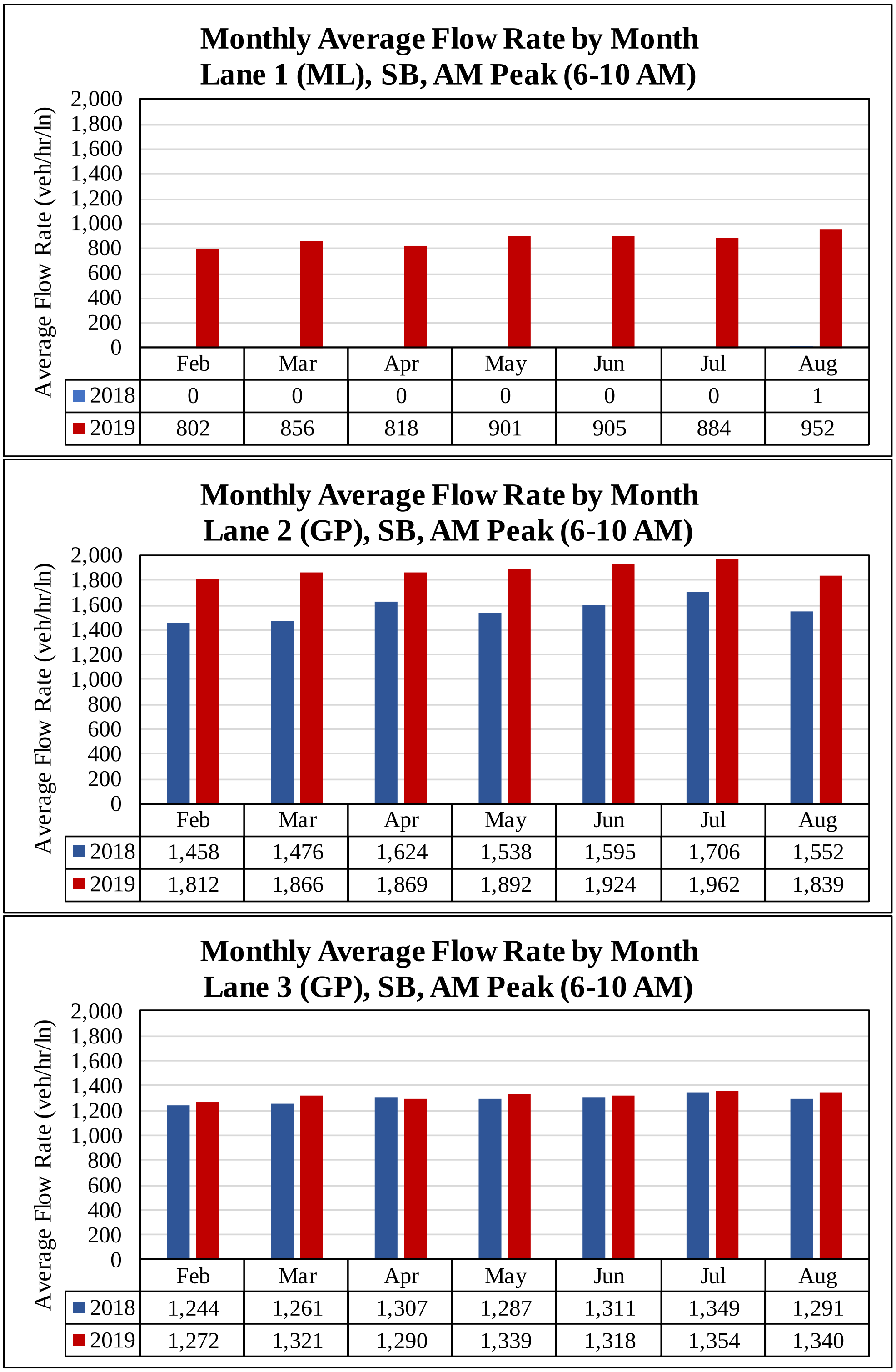
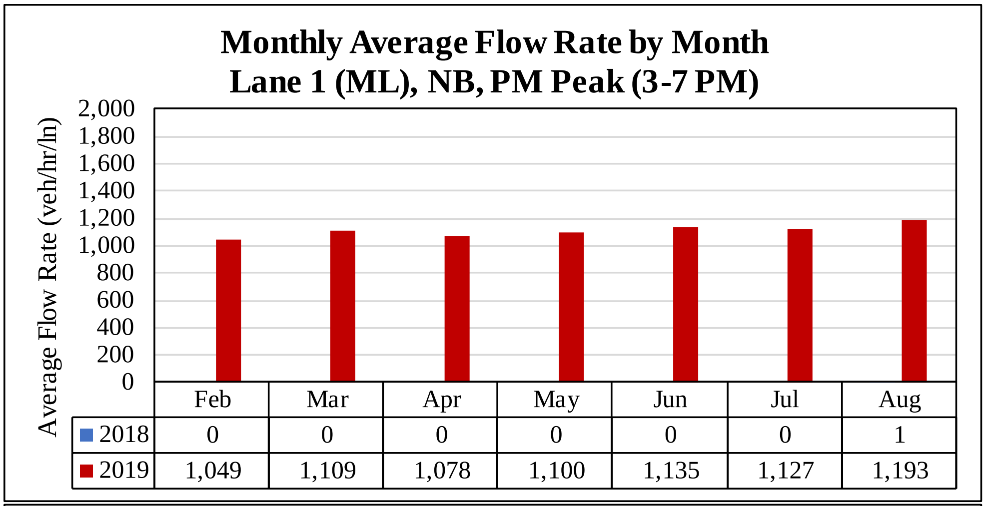
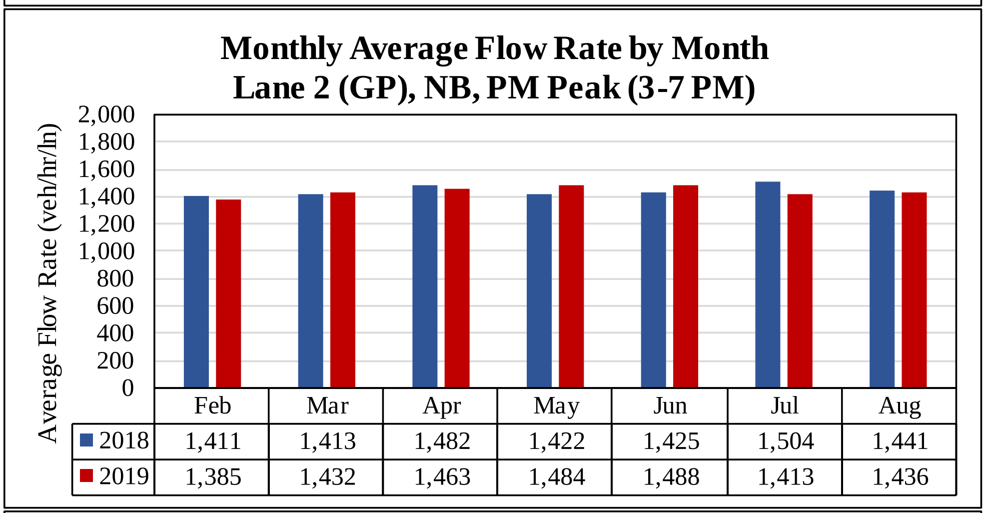


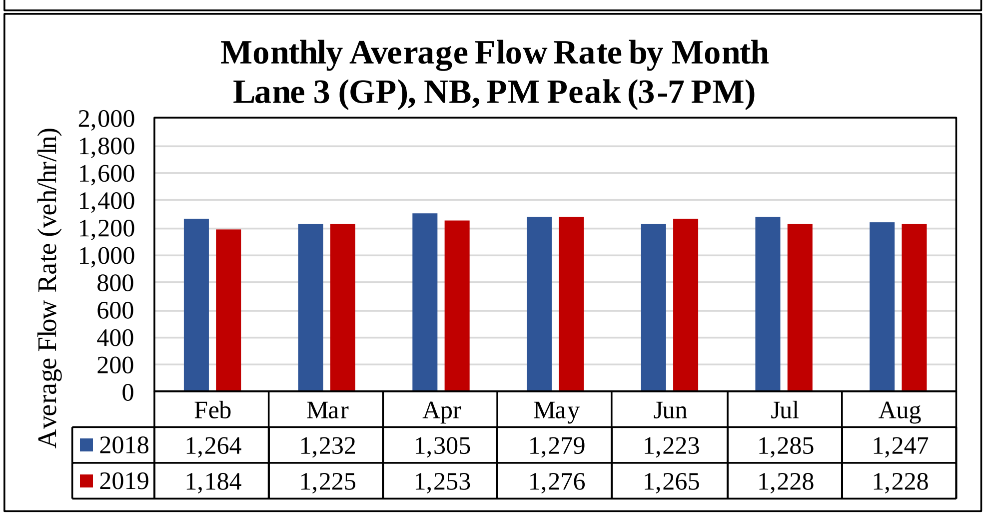
Figure 32. Average Flow Rate by Month, Chastain Road at I-575, AM Peak (6-10 AM)



	Feb	Mar	Apr	May	Jun	Jul	Aug
2018	0	0	0	0	0	0	1
2019	1,049	1,109	1,078	1,100	1,135	1,127	1,193



	Feb	Mar	Apr	May	Jun	Jul	Aug
2018	1,411	1,413	1,482	1,422	1,425	1,504	1,441
2019	1,385	1,432	1,463	1,484	1,488	1,413	1,436



	Feb	Mar	Apr	May	Jun	Jul	Aug
2018	1,264	1,232	1,305	1,279	1,223	1,285	1,247
2019	1,184	1,225	1,253	1,276	1,265	1,228	1,228

Figure 33. Average Flow Rate by Month, Chastain Road at I-575, PM Peak (3-7 PM)

3. Cross Validation using the Parallel Site at I-75

As mentioned above, the large increase could be due to the diversion from I-75. The data of a pair of NaviGAtor devices were retrieved to provide the volumes of Chastain Road at I-75 (as shown in Figure 34), to be compared with the studied site of Chastain at I-575.

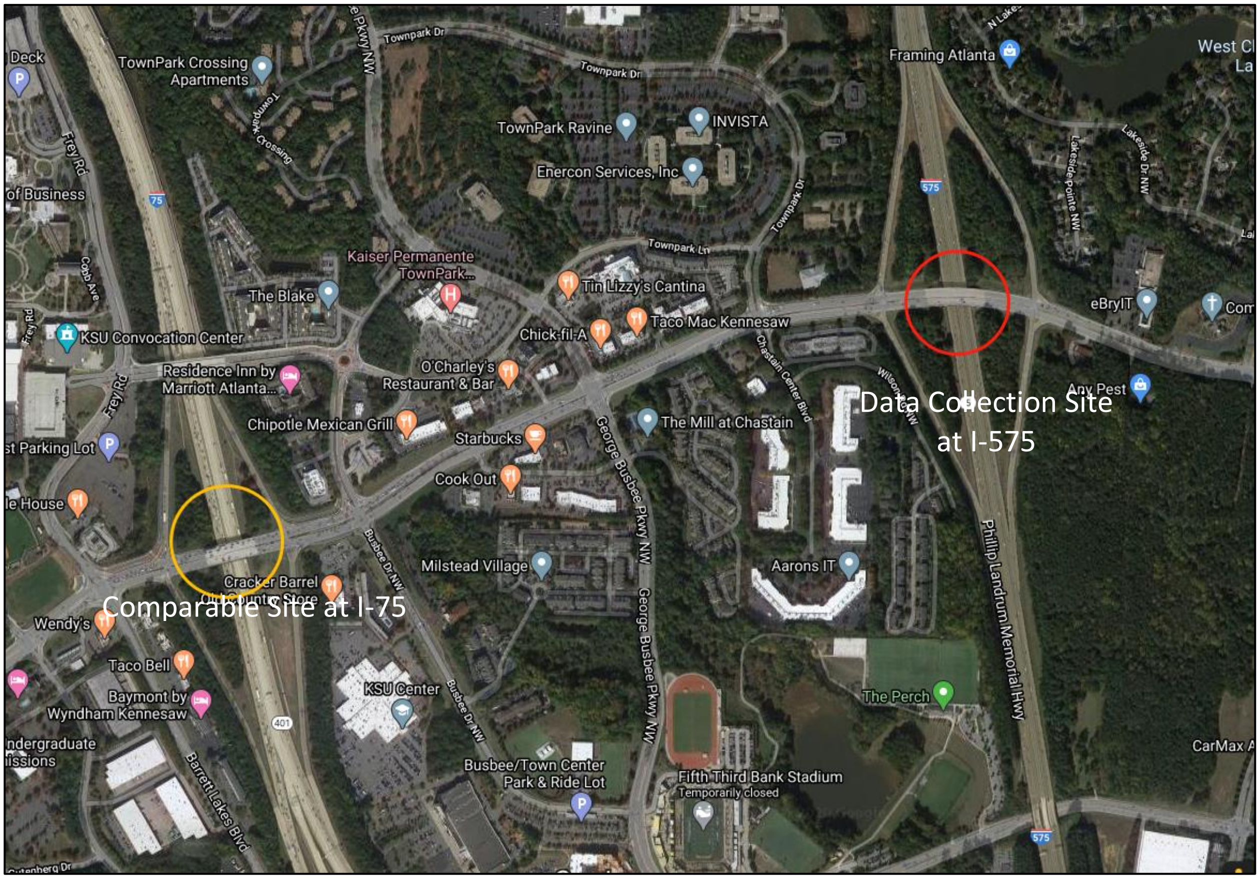


Figure 34. Comparable Site of Chastain Road at I-75 (Source: https://www.google.com/maps)

The comparable site was also found to have experienced a significant increase in traffic volumes from 2018 to 2019 (same peak hours of the same months), as shown in Table 7. The traffic flow increases on I-75 were not as large as those of I-575, but they were still large, especially in the AM peak. Hence, any diversion of traffic onto the I-575 corridor more likely came from the GA 400 corridor or from commutes along the arterial network, rather than being diverted from I-75. Although, some diversion into I-575 may have come from I-75 traffic, replaced by diversion into the I-75 from the west. It is simply not possible to determine the shifts without more detailed morning commute behavioral data at the sub-regional level. The I-575 and I-75 Express Lane both opened in September 2018, and flows are measured by different stations on these corridors, and QA/QC indicated that these traffic counts were valid.

Table 7. Changes in Daily Vehicle Throughput of the Comparable Site, Chastain Road at I-75, February-August

Direction	Lane Type	Pre-HOT Volume	Post-HOT Volume	Volume Change	Percent Change
Southbound (AM Peak)	GP	13,595	16,053	2,458	18.1%
Southbound (AM Peak)	ML	N/A	3,168	N/A	N/A
Southbound (AM Peak)	Total	13,595	19,221	5,626	41.4%
Northbound (PM Peak)	GP	17,273	16,524	-749	-4.3%
Northbound (PM Peak)	ML	N/A	3,891	N/A	N/A
Northbound (PM Peak)	Total	17,273	20,415	3,142	18.2%

4. Review of Upstream and Downstream NaviGAtor Devices

The traffic flow along the Interstate increases/decreases with the entrance and exit ramps as vehicles enter and leave the restricted highway. However, the traffic volumes at a given location can be (to some extent) reflected by analyzing both upstream and downstream traffic flow. In this step, for both directions, three adjacent NaviGAtor devices were compared with the studied site, as presented in Table 8. All upstream and downstream devices show an increase in volumes greater than 30%.

Table 8. Selected Upstream and Downstream NaviGAtor Devices

ID	Direction	Downstream/ Upstream	Description (Relative to the Studied Site)
Northbound Device #1	Northbound (PM Peaks)	Upstream	1 Mile Upstream
Northbound Device #2	Northbound (PM Peaks)	Upstream	0.6 Mile Upstream
Northbound Device #3	Northbound (PM Peaks)	Downstream	0.2 Mile Downstream
Southbound Device #1	Southbound (AM Peaks)	Upstream	1.5 Miles Upstream
Southbound Device #2	Southbound (AM Peaks)	Downstream	0.6 Mile Downstream
Southbound Device #3	Southbound (AM Peaks)	Downstream	1 Mile Downstream

The volume increases of these upstream/downstream devices from 2018 to 2019 (same peak hours and same months) are shown in Figure 35.

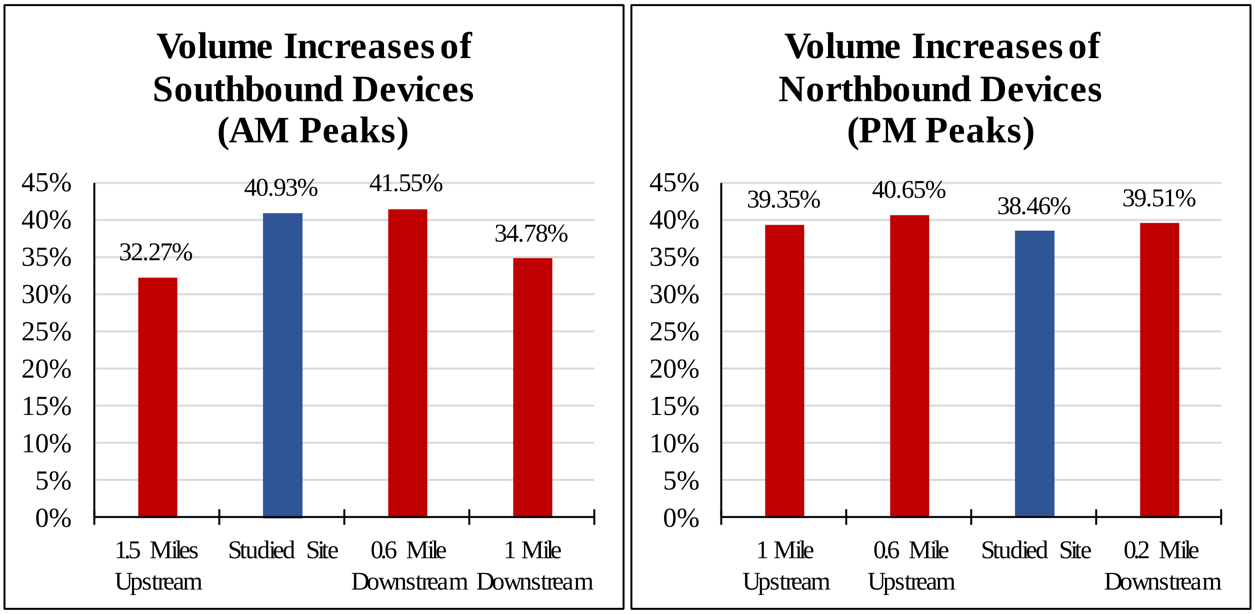
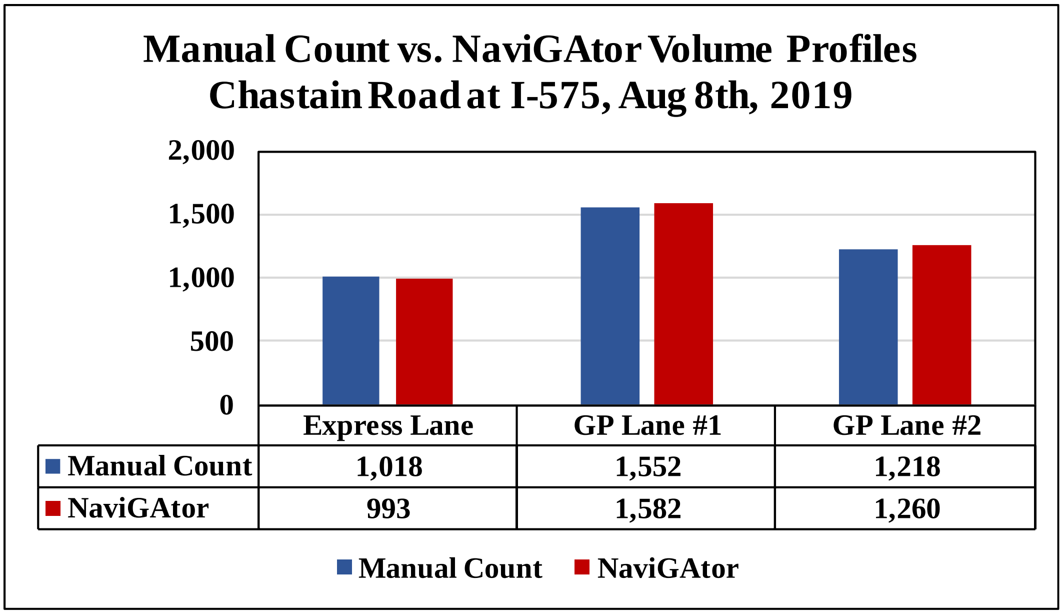


Figure 35. Percent Changes in Vehicle Throughput of Upstream and Downstream Sites

5. Video Count Quality Assurance/Quality Control (QA/QC) with Manual Count Effort and NaviGAtor Data

To verify the NaviGAtor profiles with respect to number of vehicles, the team conducted a comparison between manual count vs. provided traffic volumes based on samples of video profiles. The team randomly sampled one three-hour AM peak session on Chastain Road at I-575, and manually counted the number of vehicles by lane to compare with the NaviGAtor traffic volume (pre-processed following the methodology in section 1.1.1). The major objective of this QA/QC process is to verify the volume of the Express Lane (main cause of the large throughput increase), and the three-hour sample indicates a non-trivia contribution of the Express Lane traffic to the corridor.



	Express Lane	GP Lane #1	GP Lane #2
Manual Count	1,018	1,552	1,218
NaviGAtor	993	1,582	1,260

Figure 36. Verification of NaviGAtor Volume of the Express Lane, Chastain Road at I-575 (Sample of Aug 8th, 2019)

The team also sampled three other 10-minute sessions across all dates for the other GP lanes and found similar results as shown in Figure 37. The comparison between manual vehicle count vs. NaviGAtor did not identify any bias (i.e., any systematic overestimation or underestimation) that leads to the large throughput increase due to NaviGAtor data quality, although some of the sessions indicate a little over-counting and some under-counting, which could be due to the location discrepancy between the overpass to capture the video vs. the poles installed with NaviGAtor devices (in which case these differences can cancel each other off in a larger time period).

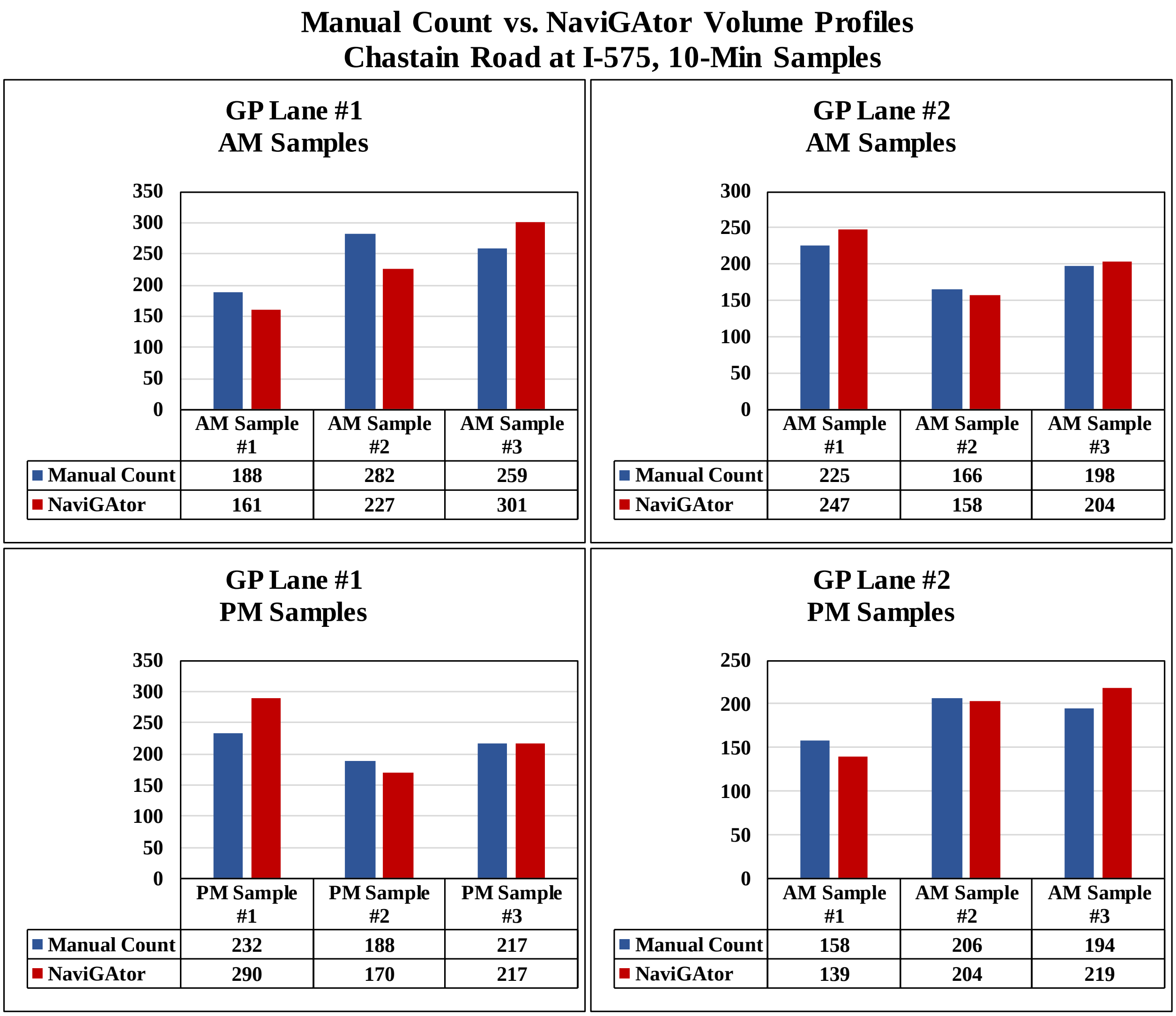


Figure 37. Manual Count vs. NaviGAtor Volume Profiles with 10-Min Samples, Chastain Road at I-575

The results of the comparisons indicate the validity of the findings with respect to the large increase on the NWC. The large increase is likely associated with the opening of Express Lanes, which may have attracted commuters from a larger region, captured drivers previously using arterial facilities (perhaps a significant share of which are commuters who diverted to other facilities due to construction and then diverted back), or induced new trips. Given that no significant expansion of the commutershed was observed (Guensler, et al. 2021b), it seems unlikely that the new Express Lanes are attracting commuters from a larger region. Given that the increase is noted in the morning commute period, it seems unlikely that the new facility is inducing significant numbers of new trips (morning peak travel is primarily composed of commute and school trips). The most likely explanation is that the congestion relief on the corridor resulted in diversion of trips from arterials to the freeway corridor and perhaps trips previously made on the shoulder of the peak into the peak after congestion decreased.

The team did not see any evidence to assert that there would be any significant changes in the total number of origin-destination pairs served by the managed lane corridor (via major land use changes or other sub-regional transportation facility construction) given the relatively short period of the before-after study. Hence, the increased morning traffic observed was not likely to have been induced by the introduction of the Express Lanes, but rather diverted from other corridors, or from shoulders of the peak periods, once users could take advantage of the significantly higher speeds provided by the new facilities (congestion declined). However, verifying this hypothesis would require more comprehensive data with better spatial and temporal coverage. As the team has suggested in previous studies, travel behavior data should be collected from a representative sample of households in a before-and-after panel study, to properly assess changes in household trip-making, destination choice, and route choice associated with construction, operation, and pricing of such managed lane facilities.

The team performed a preliminary analysis on the traffic count profiles from GDOT's TADA dataset (permanent continuous count stations). The US-41 south of Franklin Road (device ID #067-2141) was the closest downstream station that monitored highway parallel to the I-75/I-575 NWC (approximately 10 miles away from Chastain Road at I-575 and approximately 15 miles from Hickory Grove Road at I-75), and the hourly volume by time of day indicates a decrease of morning peak traffic from 2018 to 2019, as presented in Figure 38. These data did support the hypothesis of commute attracted from parallel corridors to the NWC. However, this was the only the station available on parallel corridors, and more arterial or highway data could better verify the results.

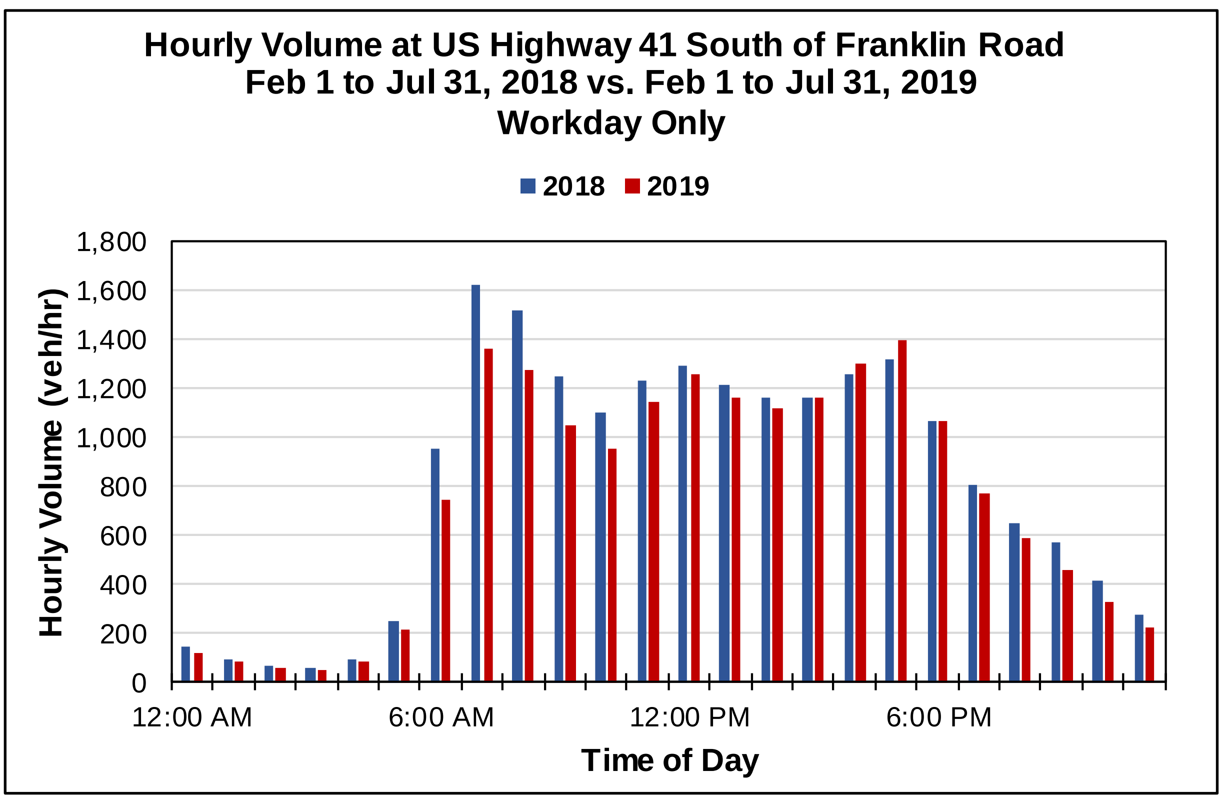


Figure 38. Hourly Volume at US Highway 41 South of Franklin Road by Time of Day

The increased throughput likely represents baseline period potential users of the Interstate who previously chose alternative arterial routes or departure times until congestion declined. Survey efforts are needed to obtain more detailed data from users about the reasons for the observed travel changes. In 2018, a discernible drop in both traffic volume and speed around 6:30 AM indicated the presence of severe congestions, while consistently higher speeds were observed in 2019, as shown in Figure 39 and Figure 40. This enhancement in 2019, coupled with the elongated increase of traffic volume in 2018, suggests that commuters previously adjusted their schedules to preempt congestion, and the alleviated conditions in 2019 allowed them to maintain their regular departure times.

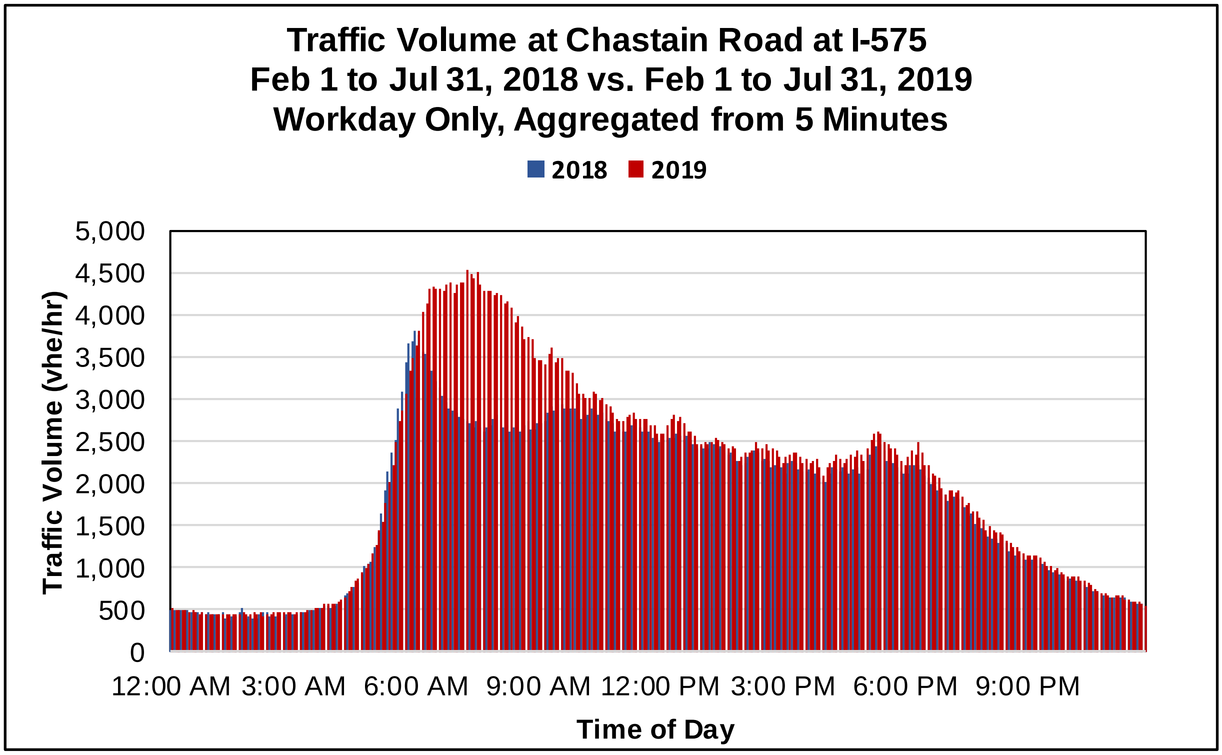


Figure 39. Hourly Volume at Chastain Road at I-575 by Time of Day

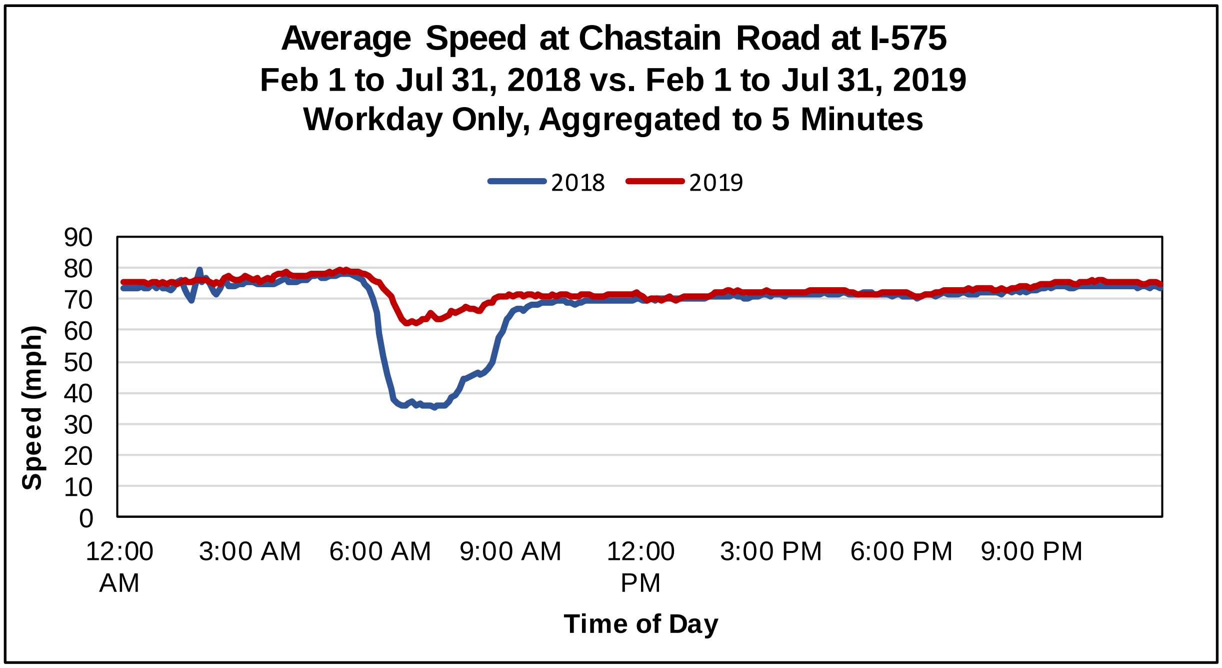


Figure 40. Average Speed for 5-Minute Bins at Chastain Road at I-575 by Time of Day

2.1.3 Impact of the Opening of Express Lane Facilities on Vehicle Throughput

The net changes in vehicle throughput at the paired control sites are shown in Table 9, which are assumed to include a base growth rate in traffic volumes in the absence of the Express Lane openings. The impact of the Express Lane openings on vehicle throughput at the test sites are derived is based on the difference-in-difference analysis (as described in the methodology chapter) as shown in Figure 41. Generally, the impacts of vehicle throughput are smaller than the net changes, which is not surprising given that the volume changes at the base stations are also positive (i.e., base growth in traffic flows across the region or sub-region).

As described in the previous chapter, Chastain Road at I-575 SB is paired with both Moores Mill Road SB (doing so results in an impact of 31.2%) and Buford Highway at I-285 WB (results in an impact of 37.6%), and the larger impact is presented in the report for a conservative estimate. The impact on both the morning peak and evening peak traffic at Chastain Road at I-575 are larger than 35%, and the impact on Hickory Grove Road at I-75 (SB) for morning peak is larger than 10%. These large increases are mostly due to the lately opened Express Lane that relieved the congestion, which may have attracted more travelers to use the corridor for their commute. The throughput impact at Hickory Grove Road (NB) is smaller than 5% for evening peaks (3.8%), which is likely due to its relatively low traffic (no major congestion before the opening). More discussions on the demand growth at NWC is provided in the next section, coupled with the before-and-after analyses of speed and emissions.

The throughput impact on Indian Trail/Lilburn Road is small (smaller than 2%) for morning peaks, which is not surprising given its distance to where the opening occurs. The impact on Old Peachtree Road is also small (less than 1%) for the morning peak, which is most likely because of its relatively low commute demand in the morning (similar to the evening traffic at Hickory Grove Road). The evening peak impact at Old Peachtree Road is 6.8% likely due to congestion relief (will be discussed in the next section), and the increase is larger than Indian Trail/Lilburn Road (6.2% of increase), which is anticipated given that Old Peachtree Road is closer to the Extension.

The evening impact at Indian Trail/Lilburn Road at I-85 is larger than 5%, which is surprising to the team given its distance to the Express Lane Extension, and given that the before-and-after commutershed analysis (Guensler et al. 2021) does not indicate a significant change in the catchment area (in terms of the size and location). The paired control site (Shallow Ford Road at I-85 NB) has a minor volume growth of only 2.3%, but the team did not find it to be an inappropriate match. The control site is located approximately ten miles upstream of Indian Trail Lilburn Road (which is further away from the Express Lane Extension), and is unlikely to be influenced by the Extension while keeping a decent similarity to the control site (same corridor). The team also did not see a significant change in the average speed by hour at the test site, indicating that the Express Lane opening did not cause a further speed decrease, even though 6.2% more traffic was attracted to the corridor.

Table 9. Net Changes in Vehicle Throughput at the Control Sites

Control Site	Paired Peak Hours	Net Change
Shallow Ford Road at I-85 NB	PM (3-7 PM)	2.7%
Moores Mill Road at I-75 SB	AM (6-10 AM)	8.8%
Buford Highway at I-285 WB	AM (6-10 AM)	3.8%
University Avenue at I-75/I-85 SB	PM (3-7 PM)	1.8%
Buford Highway at I-285 EB	AM (6-10 AM)	7.7%

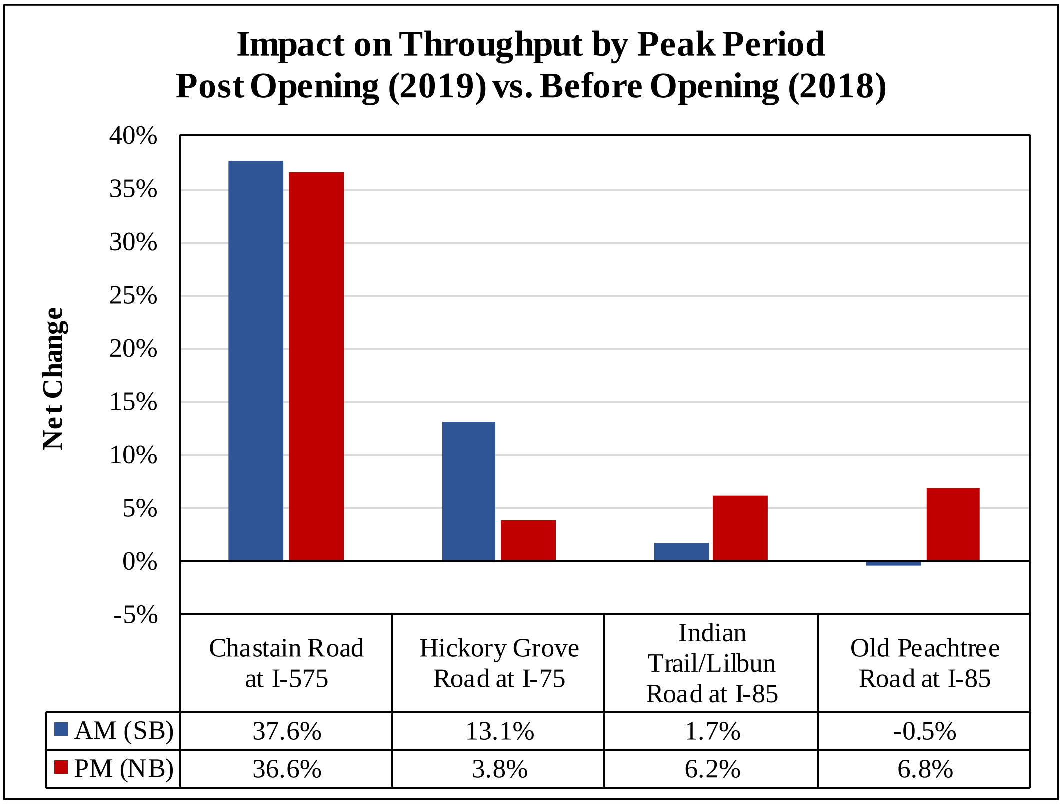


Figure 41. Impact of Express Lane Openings on Vehicle Throughput by Site

2.2 Energy use and emissions Modeling Results

The net changes in energy use and emissions (CO, NOx and PM2.5) at the test sites are shown in Figure 42, Figure 43, Figure 44 and Figure 45, respectively. The full results of all pollutants can be found in Appendix A. Pairing Chastain Road at I-575 SB with Moores Mill Road at I-75 SB (presented in this section) results in a more conservative estimate of emission impacts than Buford Highway at I-285, and the impacts based on pairing with Buford Highway at I-285 WB is presented in the appendix. Generally, the changes in emissions are smaller than the throughput changes, especially for the NWC (Chastain Road at I-575 and Hickory Grove Road at I-75). The increases of emissions at Chastain Road at I-575 are only 11.4% to 27.0% for morning peaks, and only 7.3% to 20.3% for evening peaks, while the throughput increases are larger than 40%. The emissions only changed -0.1% to 5.5% at Hickory Grove Road for morning peaks, with a throughput increase of 21.8%. Similar findings were observed at other test sites too, except for the morning peak at Old Peachtree Road at I-85, where CO emissions increased 11.1% even though the vehicle throughput only increased 7.2% (due to high-speed impacts).

The unproportioned emission changes are due to speed changes that occurred concurrently with the volume (speed-flow rate relationship), as shown in Figure 46 through Figure 53. With the new Express Lanes on the NWC and the extended Express Lanes on I-85, the average travel speed increased at peak hours (traffic diverted to the new lanes), and these changes further lead to a larger decrease of emissions that compensate the volume increase due to the non-linear relationship between speed and emission factors.

Sample speed-emission rate relationships of CO, CO_2 (equivalent to energy use), NO_x and $PM_{2.5}$ are shown in Figure 54 (Lu et al. 2019). It is indicated that emission rates decrease as average speeds rise to around 30 to 40 mph, and the emission rates stay relatively stable until high speed ranges of 60+ mph when the emission rates increase again due to wind load. Although the particular curves vary (in terms of how large the increase/decrease are and at what speed they occur) depending on temperature, humidity, source types (fleet composition), model year, etc., this relationship applies as a general trend and can be used to help interpret the before-and-after analysis, and the variability of emission changes across various pollutants at the same test site is due to the variances of the speed-emission rate relationships across the pollutants.

It is worth noting that a decrease in speed does not always lead to a significant increase in emissions due to the non-linear relationships for emission rates. For example, the speeds at Hickory Grove Road at I-75 NB decreased from approximately 80 to 70 mph and emission rates decreased because the wind load on these vehicles decreased. Similarly, increased speeds can sometimes increase emission rates when speeds are high enough, which is why the emissions increased at Old Peachtree Road at I-85 for evening peaks increased when congestion relief led to free-flow speeds of approximately 70 mph. However, for most corridors, congestion relief led to lower emissions rates. Over the long term, with continued exurban development and growth in vehicle miles of travel, further increases in traffic volumes are likely to be observed along these major commute corridors and energy use and emissions will increase.

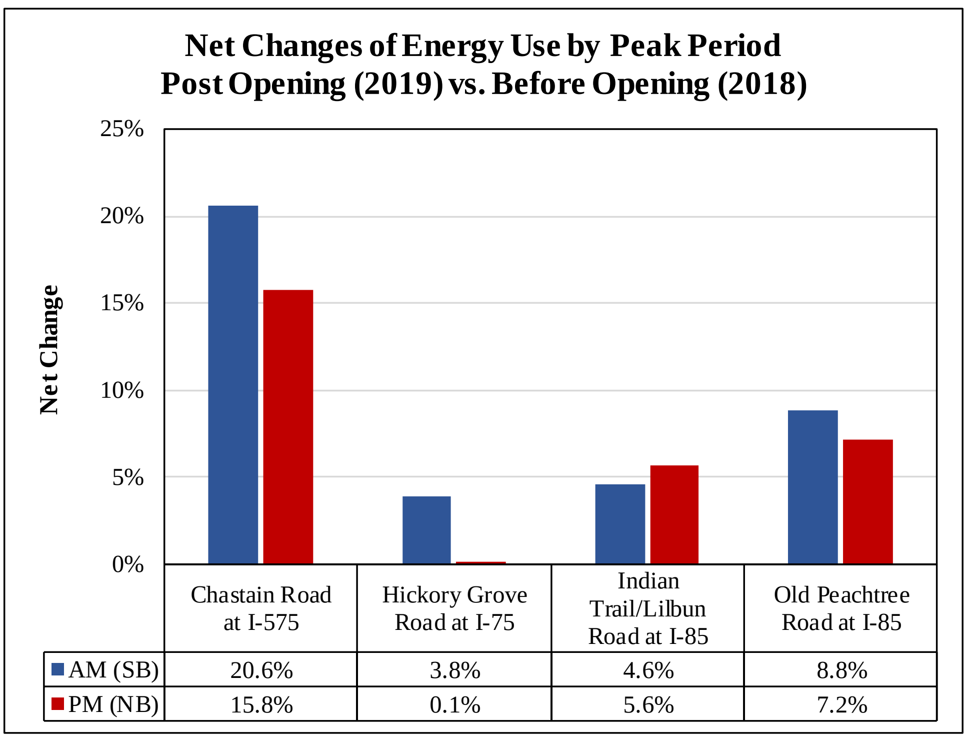
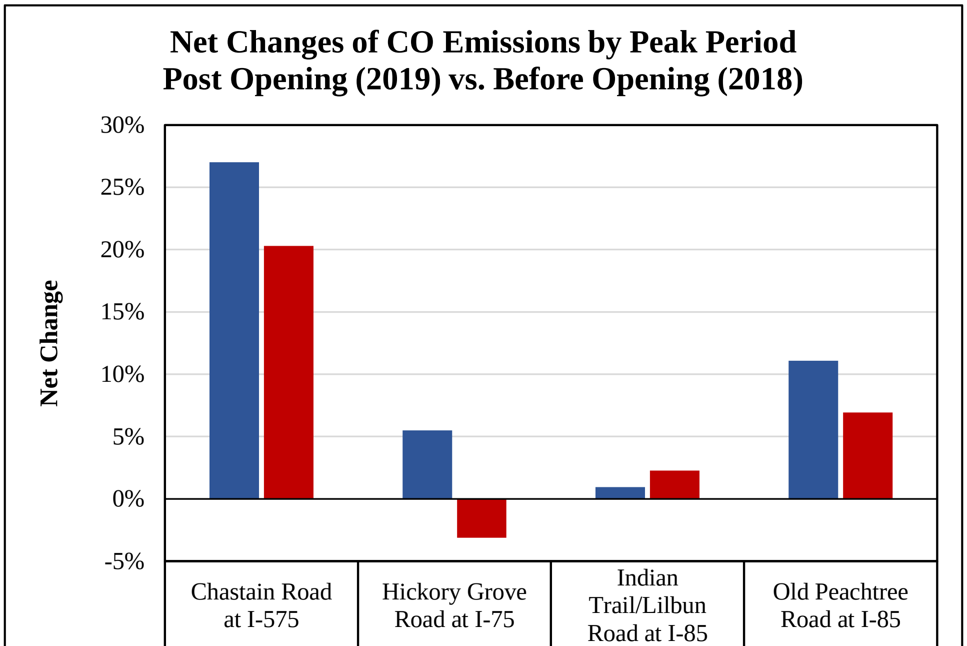
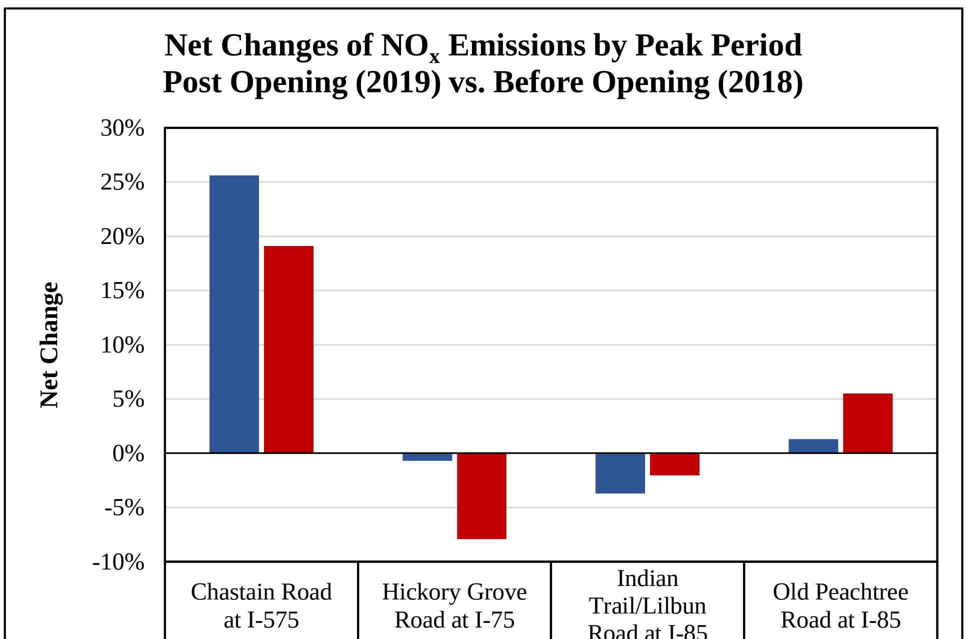


Figure 42. Net Change Percentage of Energy Use by Site



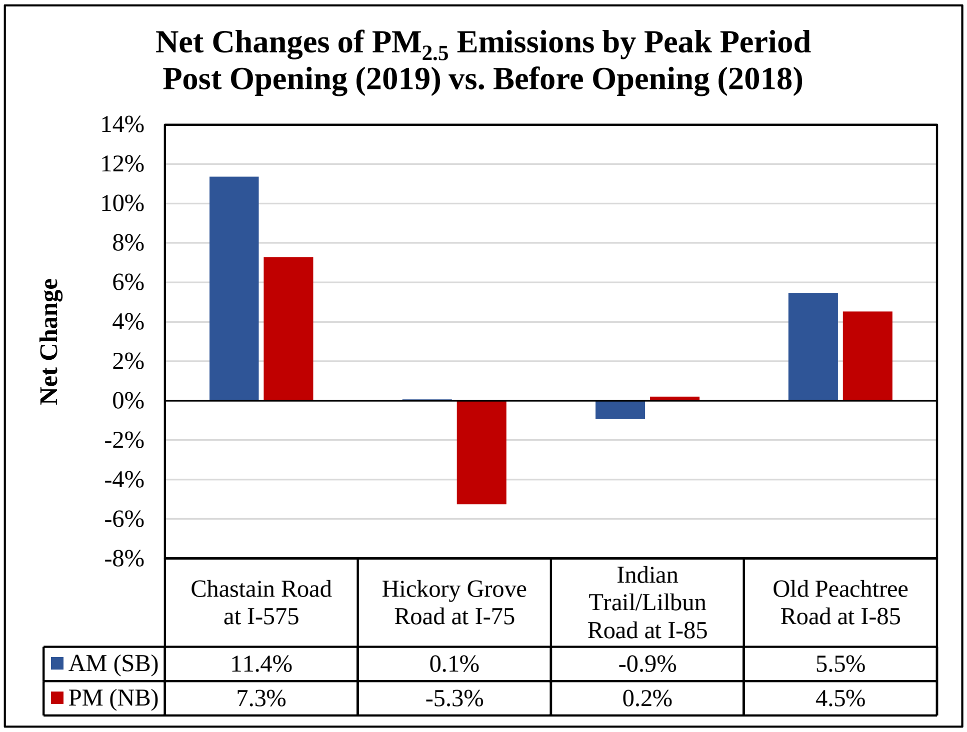
	Chastain Road at I-575	Hickory Grove Road at I-75	Indian Trail/Lilbun Road at I-85	Old Peachtree Road at I-85
AM (SB)	27.0%	5.5%	1.0%	11.1%
PM (NB)	20.3%	-3.1%	2.3%	6.9%

Figure 43. Net Change Percentage of CO Emissions by Site



	Chastain Road at I-575	Hickory Grove Road at I-75	Indian Trail/Lilbun Road at I-85	Old Peachtree Road at I-85
AM (SB)	25.6%	-0.7%	-3.7%	1.3%
PM (NB)	19.1%	-7.9%	-2.0%	5.5%

Figure 44. Net Change Percentage of NOx Emissions by Site



	Chastain Road at I-575	Hickory Grove Road at I-75	Indian Trail/Lilbun Road at I-85	Old Peachtree Road at I-85
AM (SB)	11.4%	0.1%	-0.9%	5.5%
PM (NB)	7.3%	-5.3%	0.2%	4.5%

Figure 45. Net Change Percentage of PM2.5 Emissions by Site

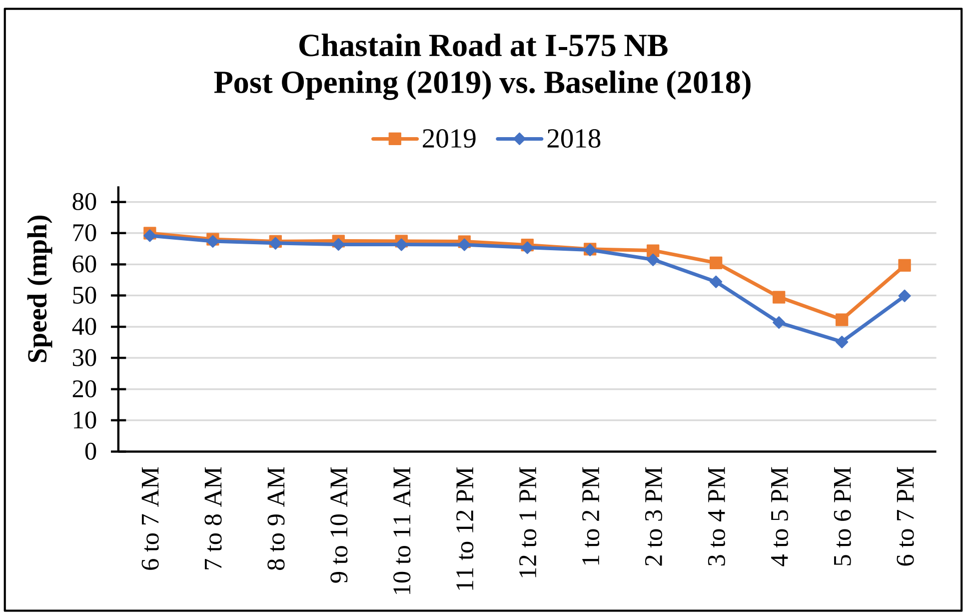


Figure 46. Changes in Average Speed by Hour at Chastain Road at I-575 NB, Post-opening (2018) vs. Pre-opening (2018)

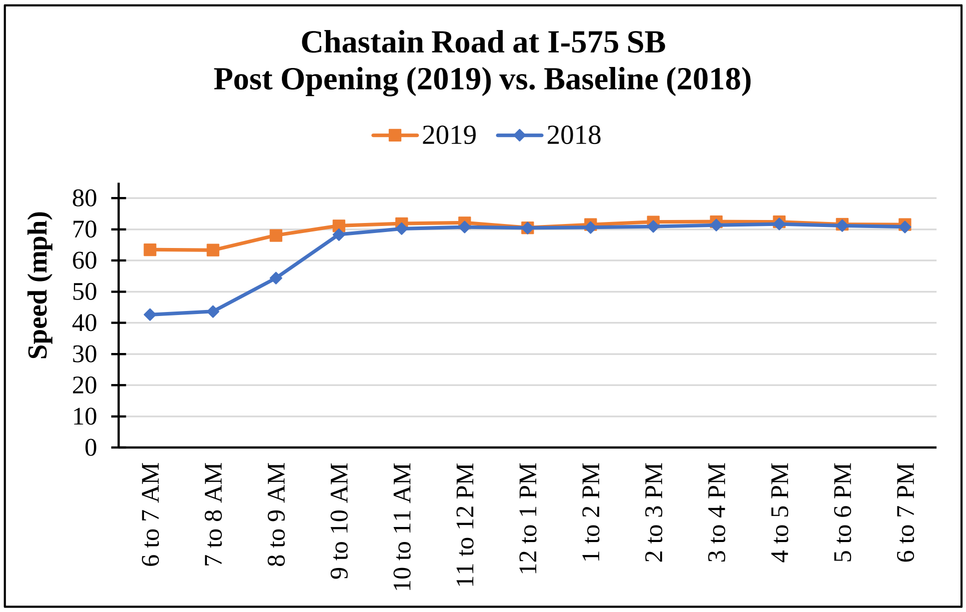


Figure 47. Changes in Average Speed by Hour at Chastain Road at I-575 SB, Post-opening (2018) vs. Pre-opening (2018)

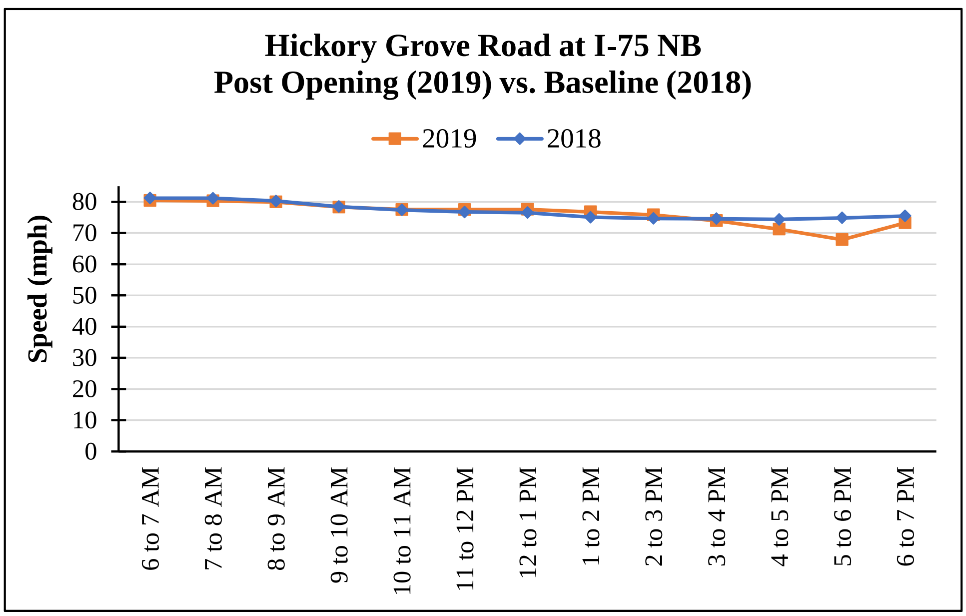


Figure 48. Changes in Average Speed by Hour at Hickory Grove Road at I-75 NB, Post-opening (2018) vs. Pre-opening (2018)

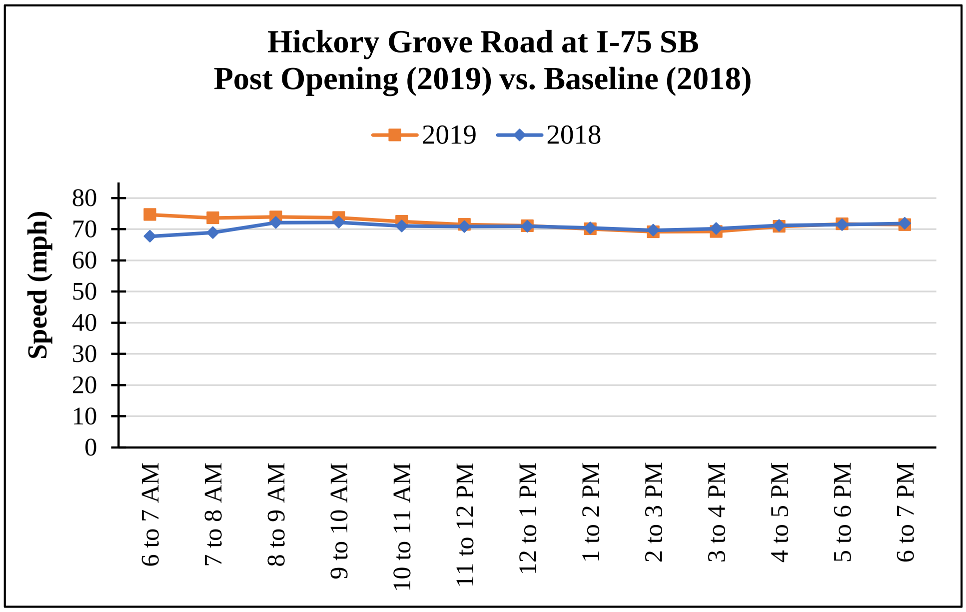


Figure 49. Changes in Average Speed by Hour at Hickory Grove Road at I-75 SB, Post-opening (2018) vs. Pre-opening (2018)

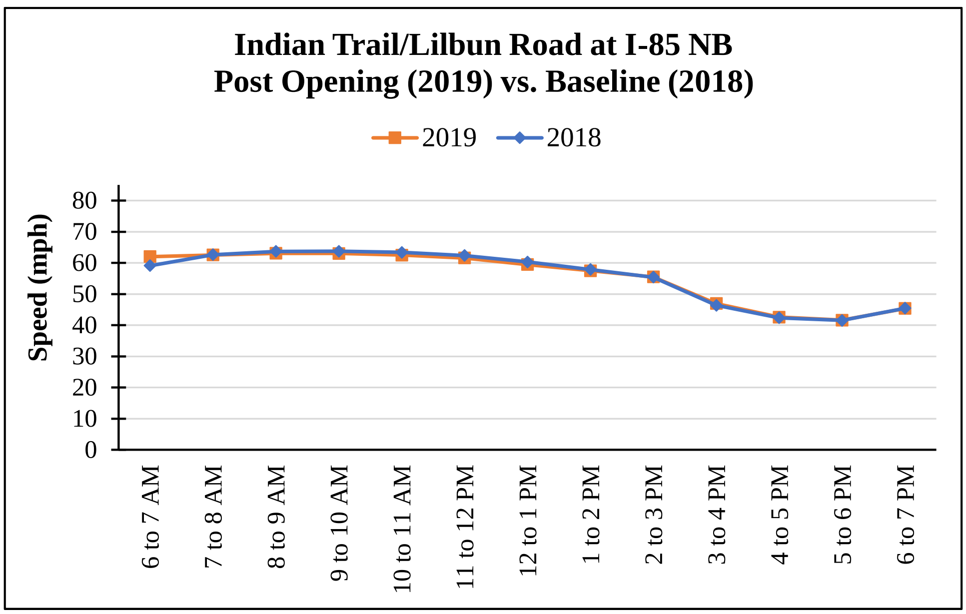


Figure 50. Changes in Average Speed by Hour at Indian Trail/Lilburn Road at I-85 NB, Post-opening (2018) vs. Pre-opening (2018)

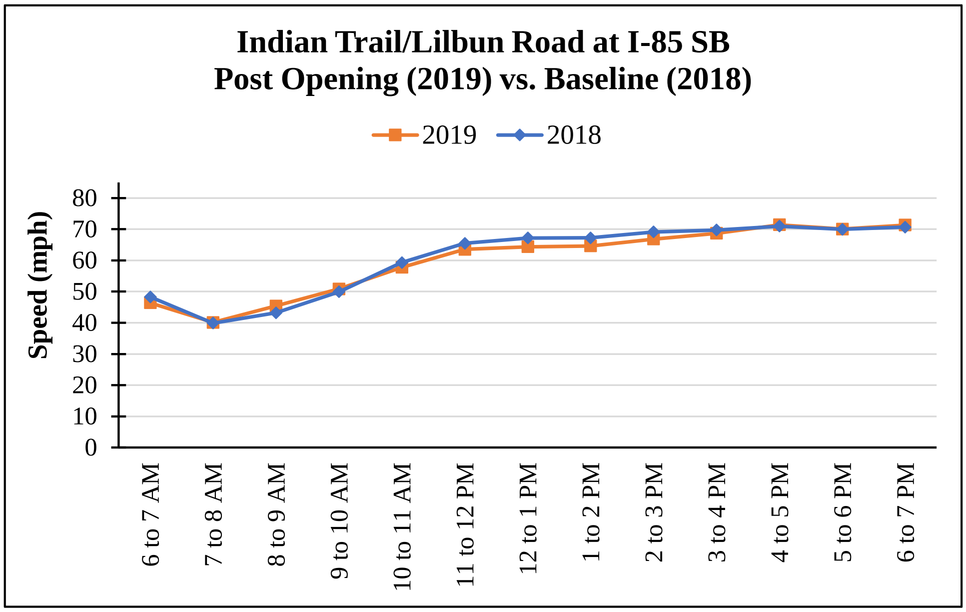


Figure 51. Changes in Average Speed by Hour at Indian Trail/Lilburn Road at I-85 SB, Post-opening (2018) vs. Pre-opening (2018)

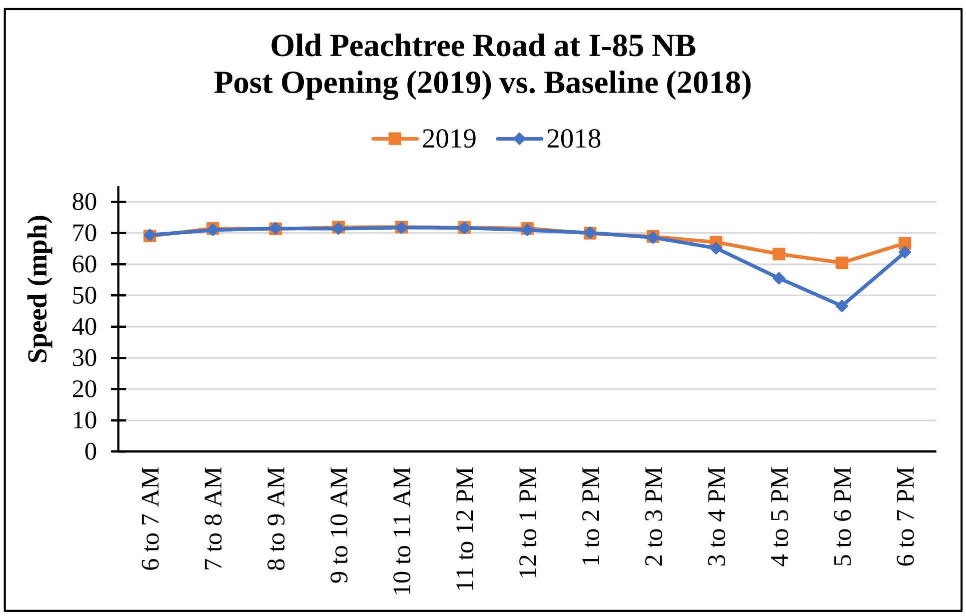


Figure 52. Changes in Average Speed by Hour at Old Peachtree Road at I-85 NB, Post-opening (2018) vs. Pre-opening (2018)

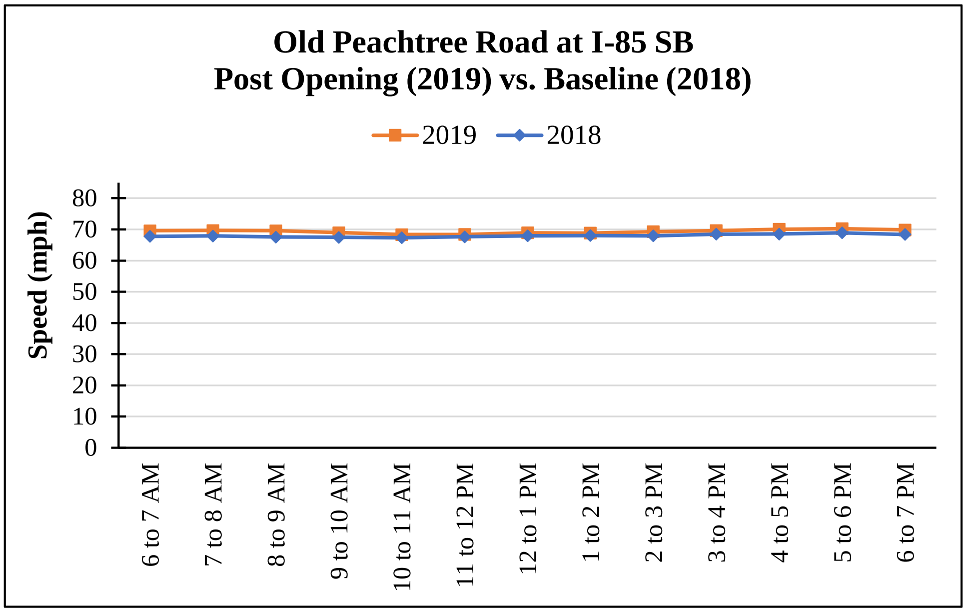


Figure 53. Changes in Average Speed by Hour at Old Peachtree Road at I-85 SB, Post-opening (2018) vs. Pre-opening (2018)

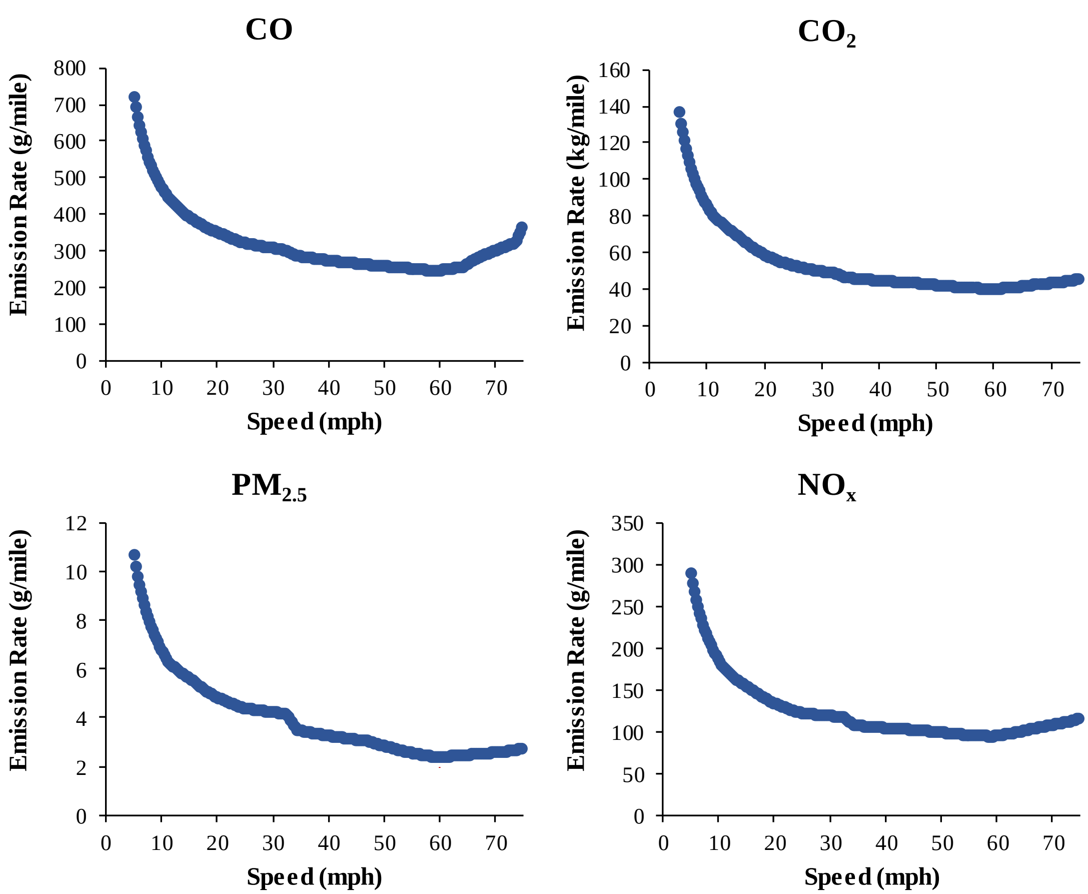


Figure 54. Sample Speed-Emission Rate Relationships of CO, CO2, PM2.5 and NOx

The improvement of engine technology from 2018 to 2019 also contributes to the reduced emissions, and factors like this (constant change in emissions in the absence of the Express Lane Openings) are accounted for based on the difference-in-difference analysis of the control sites, as shown in Table 10. Similar with the test sites, the emission changes are not proportional to the throughput changes due to the relationships of speed-flow rate and of speed-emission rates. The decreases of emissions in the table indicate that newer vehicles have lower emission rates, and the technology improvement compensates the volume increases.

The energy use and emissions impact of the openings after excluding the constant changes are shown in Figure 55 (energy use), Figure 56 (CO), Figure 57 (NO_x) and Figure 58 ($PM_{2.5}$). The impacts at Hickory Grove Road at I-75 (both morning and evening peak periods), Indian Trail/Lilburn Road at I-85 (morning peaks) and Old Peachtree Road at I-85 (morning peaks) are negative, and it indicates that the Express Lane facilities are helping reduce the emissions (by providing faster travel speed). It is important to note that even with a throughput increase of more than 20%, the emissions actually decreased at Hickory Grove Road for morning peaks, because the speed increase due to the Express Lane opening compensates the large throughput increase. The impact at Indian Trail/Lilburn Road at I-85 for evening peaks are smaller than 3%, indicating a minor increase due to the opening (slight volume increase), and the impact at Old Peachtree Road at I-85 are larger than 5% for evening peaks, which is due to the congestion relief (speed increases near free-flow speed) that increased the emission rates.

Although the emission impact at Chastain Road at I-575 can be larger than 20% for NO_x (morning and evening peaks) and CO (morning peaks), the impacts on $PM_{2.5}$ are only approximately 10% to 15% (variability across pollutants), it does not indicate an overall negative impact of the on the environment. The Express Lane openings diverted traffic from other facilities (which are likely to have lower speed), and contributed to relieving the congestions on more facilities than only the I-575 corridor. It could be that the emissions of these facilities are reduced, and an overall impact of the Express Lane opening is negative. This is likely given the large increase of volume at I-575 (i.e., a likely large decrease of volume in parallel facilities), and given that the emission rates on arterials are much higher than restricted highway. Traveling on Interstate highway is more energy efficient and environment friendly at the same speed compared with arterials/local roads, due to the absence of flow interruption (stop signs, signalization, etc.). However, the team cannot verify the overall impact due to a lack of traffic operation data on arterials and local roads near the test sites.

Table 10. Net Changes in Emissions at the Control Sites

Control Site	Paired Peak Hours	CO	NO_x	$PM_{2.5}$
Shallow Ford Road at I-85 NB	PM (3-7 PM)	-0.3%	-4.2%	-2.2%
Moores Mill Road at I-75 SB	AM (6-10 AM)	-3.0%	-6.1%	-2.0%
Buford Highway at I-285 WB	AM (6-10 AM)	3.5%	-0.3%	1.5%
University Avenue at I-75/I-85 SB	PM (3-7 PM)	4.5%	-0.9%	4.5%
Buford Highway at I-285 EB	AM (6-10 AM)	9.7%	3.7%	7.4%

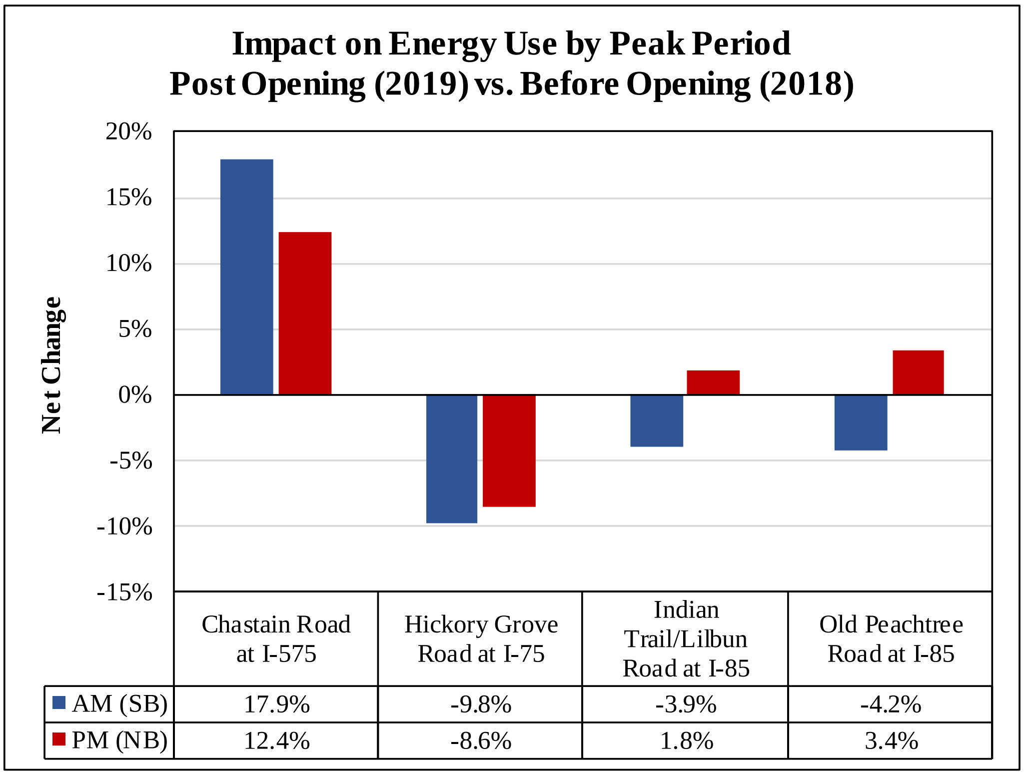


Figure 55. Impact of Express Lane Openings on Energy Use by Site

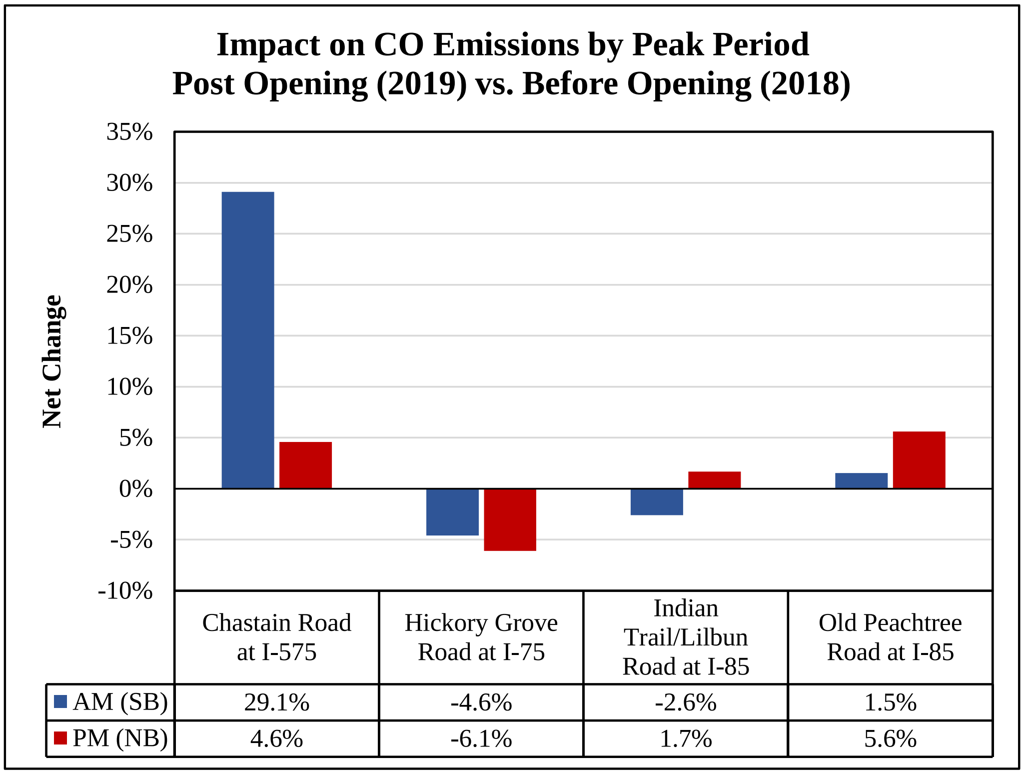


Figure 56. Impact of Express Lane Openings on CO Emissions by Site

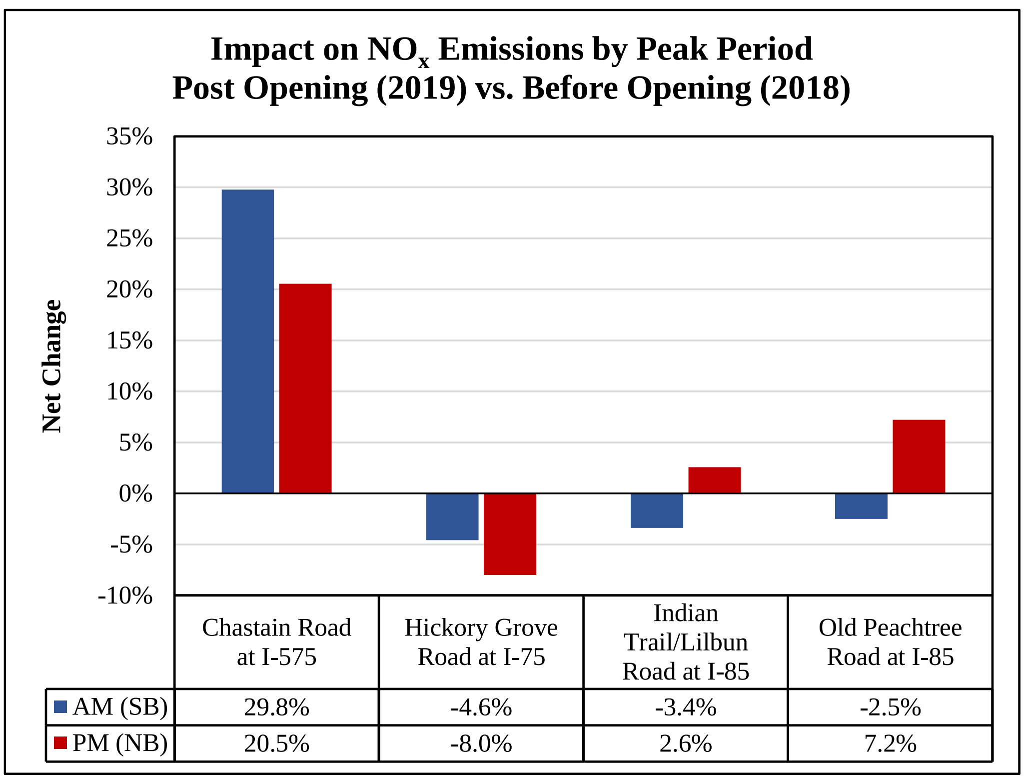
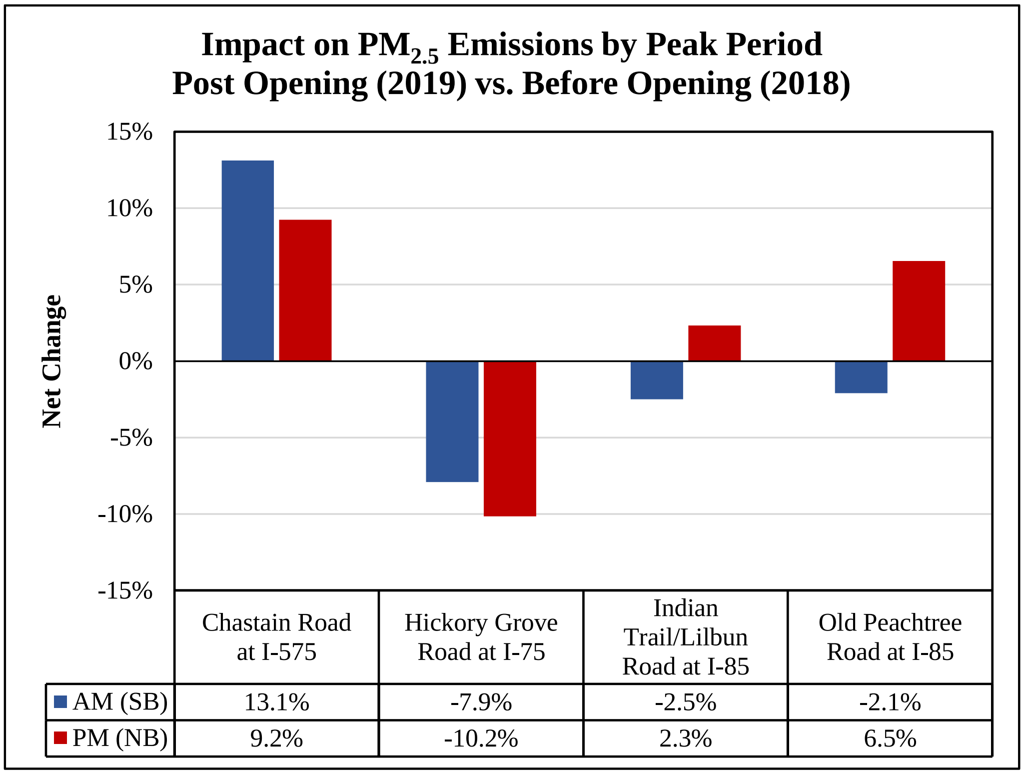


Figure 57. Impact of Express Lane Openings on NOx Emissions by Site



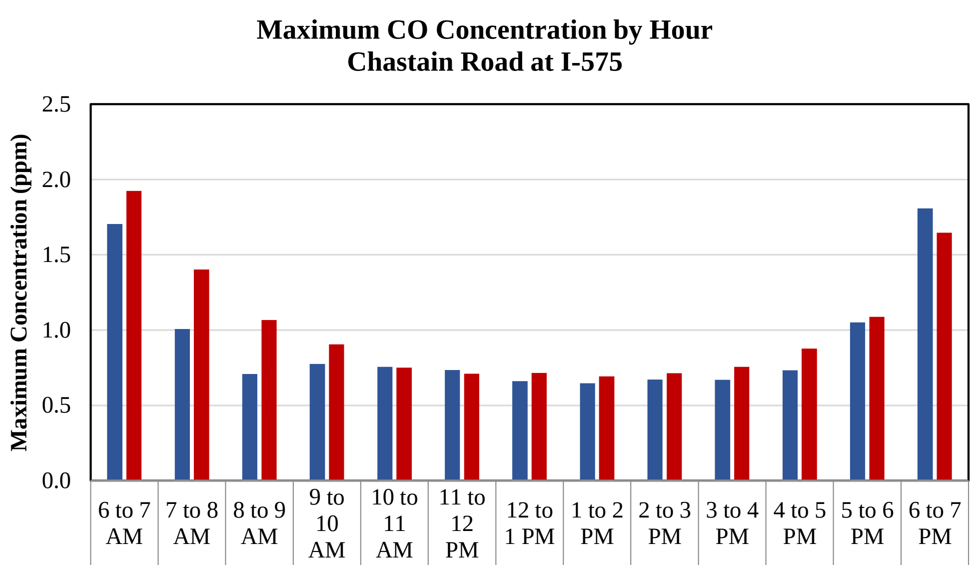
	Chastain Road at I-575	Hickory Grove Road at I-75	Indian Trail/Lilbun Road at I-85	Old Peachtree Road at I-85
AM (SB)	13.1%	-7.9%	-2.5%	-2.1%
PM (NB)	9.2%	-10.2%	2.3%	6.5%

Figure 58. Impact of Express Lane Openings on PM2.5 Emissions by Site

2.3 Dispersion Modeling Results

The hourly maximum concentrations of CO predicted by AERMOD is shown in Figure 59, and the before-and-after comparison indicates an overall increase, especially during the morning peaks. The maximum daily concentration increased from 1.81 ppm to 1.93 ppm, and the hour with highest concentration shifted from 6 to 7 PM slot in 2018 to 6 to 7 AM in 2019, which is not surprising given the large increase of morning peak throughput. (maximum concentration of 6 to 7 PM decreased from 1.81 to 1.65 ppm). As discussed in the previous section, the Express Lane opening at I-575 diverted a lot more vehicles from other facilities, and one of cons of having large traffic volumes is the increase of pollutant concentrations, even though the emission rates decreased, and overall emissions likely decreased (if other facilities where the throughput decreased were accounted for).

The team cannot conclude whether or not the predicted concentration profiles raise concerns with respect to the impact of the Express Lanes at Chastain Road at I-575, given a lack of background concentration data. It is likely that the concentration was reduced at areas near the facilities where traffic was diverted from, but the team cannot verify this as well given the poor data availability of arterial and local roads.



	6 to 7 AM	7 to 8 AM	8 to 9 AM	9 to 10 AM	10 to 11 AM	11 to 12 PM	12 to 1 PM	1 to 2 PM	2 to 3 PM	3 to 4 PM	4 to 5 PM	5 to 6 PM	6 to 7 PM
2018	1.70	1.01	0.71	0.78	0.76	0.73	0.66	0.65	0.67	0.67	0.73	1.05	1.81
2019	1.93	1.40	1.07	0.91	0.75	0.71	0.72	0.69	0.71	0.76	0.88	1.09	1.65

Figure 59. Maximum CO Concentration by Hour at Chastain Road at I-575 (Both Approaches), Pre-Opening (2018) vs. Post-Opening (2019)

3. Conclusions and Future Work

This study assessed the energy use and emissions changes after the opening of reversible toll lanes on the I-75/I-575 NWC and the HOT lane extension at I-85 of Atlanta, GA, and assessed the energy and emission impact of the new facilities by developing and analyzing the counterfactual scenarios based on control sites along the corridors of I-75, I-85, I-75/I-85, I-285, and GA-400. The project is an extension of the project entitled "Energy and Environmental Impacts of Atlanta's Reversible Express Toll Lanes and High-Occupancy Toll Lanes" as documented in agency reports (Guensler, et al., 2021a and 2021b).

The test sites included Chastain Road at I-575, Hickory Grove Road at I-75, Indian Trail/Lilburn Road at I-85, and Old Peachtree Road at I-85. The research team tracked changes in vehicle throughput on the managed lane corridors (extracted from GDOT's Georgia NaviGAtor machine vision system after comprehensive QA/QC) and performed a difference-in-difference analysis to exclude regional changes. Each test site was paired with control sites on I-285, I-75/I-85, and I-85 based upon speed and flow rate variability by time of day. Pairing Chastain Road at I-575 for the morning peak was challenging, given the small size of the control site pool, but better control sites were simply not available.

Data analyses indicated that vehicle throughput on these managed lane corridors increased significantly after the Express Lanes opened. Vehicle throughput increased by more than 35% at Chastain Road at I-575 in both the morning and evening peaks. Adding the new Express Lane capacity significantly relived congestion, increasing vehicle speeds during the morning peak by more than 20 mph and by around 5 mph in the evening peak. The increase in vehicle throughput must mean that either a significant increase in trip generation occurred during the morning peak (new trips not made prior to the Express Lane opening), or that congestion reductions were so great that existing traffic diverted into the corridor during the morning peak, or some combination thereof. Given that morning peak traffic is dominated by work and school trips, it seems unlikely that increases in throughput is related to new trip generation, but latent demand increases in the afternoon peak certainly cannot be ruled out. Given the very large improvements in Interstate vehicle speeds, it seems likely that commute traffic diverted onto these corridors from parallel arterials or from the shoulders of the peak.

Unfortunately, without overall control volume totals and/or pre-and-post travel behavior surveys for the alternative commute routes, it is not possible to quantify the likely reductions in traffic flow and emissions that occurred along the other corridors that likely resulted from shifts in morning commutes. Hence, the team cannot draw reliable conclusions related to net regional or sub-regional impacts associated with the new managed lane corridors. The impact observed on the I-85 corridor was much smaller than on the NWC, especially at Indian Trail/Lilburn Road (far from the Express Lane Extension).

Despite the large volume increase, the net increases in energy use and emissions are smaller, given the reduction in congestion that reduces vehicle emission rates (grams/vehicle-mile). This is not surprising, as changes in emission rates are not proportional to changes in traffic volumes (emission rates are also a function of traffic conditions). Given that these Express Lane facilities are attracting travelers from a larger catchment area (Guensler et al. 2021) and pulling traffic from congested arterial corridors, it is possible that the overall impact on the sub-region may actually be decrease in energy use and emissions. However, the team cannot quantify the overall impact at the sub-region or regional level, due to a lack of speed and volume profiles of arterials and local roads and lack of information on how commute changes affected other freeway corridors.

Although the net changes in vehicle throughput is 21.8% at Hickory Grove Road at I-75 for the morning peaks, the impact of the openings only contributed an increase of 13.1% (congestion decreased), and the impact on evening throughput is only 3.8% (which was uncongested prior to opening). Due to the speed increases, the opening reduced the energy use and emissions for both morning peaks (-4.6% to -9.8%) and evening peaks (-6.1% to -10.2%). The case study of dispersion modeling indicates an increase of maximum concentration from 1.81 ppm to 1.93 ppm, and the maximum hour shifted from 6 to 7 PM to 6 to 7 AM. These changes are small, and the before-and-after concentrations are both very low.

The throughput impact of the Extension on I-85 (Indian Trail/Lilburn Road and Old Peachtree Road) are not as large as NWC, and the impact on morning peaks (smaller than 2%) are smaller than evening peaks (approximately 6%). The emission and energy impacts are also small for both morning peaks (small decrease except for a 1.5% increase of CO emissions at Old Peachtree Road for morning peaks) and evening peaks (no larger than 7.5%). The impact on Old Peachtree Road is larger than Indian Trail/Lilburn Road, which is anticipated given their distances to the Express Lane Extension.

Overall, the opening of the Express Lane facilities increased the travel speed, and (for most sites) attracted more travelers, especially on the NWC. Unfortunately, team cannot draw any conclusions on the overall energy use and emissions impact from the Express Lanes at the sub-regional or regional level, until more comprehensive commute activity and traffic operations data can be obtained for nearby arterials and local roads and other freeway corridors. Before-and-after travel behavior studies are needed, if such conclusions are desired.

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Data Summary

As described in this report, the team modeled changes in energy use and emissions using traffic operations data collected by the State Department of Transportation and energy and emission rates derived by the research team from more than 130,000 MOVES 2014b model runs.

Products of Research

The traffic volume and speed data used in this study were collected by the Georgia Department of Transportation (GDOT). Under the data user agreement, interested parties need to obtain NaviGAtor data from GDOT. The energy and emission rate matrices applied to the NaviGAtor data are public domain and can be found at https://doi.org/10.5281/zenodo.13381895.

Data Format and Content

The format and content of the MOVES-Matrix (MOVES2014b) data sets are documented in the NCST MOVES-Matrix overview and training documents https://github.com/gti-gatech/moves_training.

Data Access and Sharing

The MOVES-Matrix data are open source and can be downloaded and freely shared from the link provided above.

Reuse and Redistribution

The MOVES-Matrix data are open source can be downloaded, used, and freely redistributed using the link provided above.

Appendix A: Net Changes in Vehicle Throughput, Emissions and Energy Use

Table 11. Net Changes at the Test Sites

Test Site	Peak Hours	Throughput	CO	NO_x	VOC	PM_{10}	$PM_{2.5}$
Chastain Road at I-575	AM (6-10 AM)	42.8%	27.0%	25.6%	-1.8%	11.9%	11.4%
Hickory Grove Road at I-75	AM (6-10 AM)	21.8%	5.5%	-0.7%	-7.6%	0.2%	0.1%
Indian Trail/Lilburn Road at I-85	AM (6-10 AM)	5.6%	1.0%	-3.7%	-8.2%	-0.9%	-0.9%
Old Peachtree Road at I-85	AM (6-10 AM)	7.2%	11.1%	1.3%	-1.4%	5.6%	5.5%
Chastain Road at I-575	PM (3-7 PM)	2.7%	20.3%	19.1%	-4.6%	7.7%	7.3%
Hickory Grove Road at I-75	PM (3-7 PM)	1.8%	-3.1%	-7.9%	-10.4%	-5.2%	-5.3%
Indian Trail/Lilburn Road at I-85	PM (3-7 PM)	2.7%	2.3%	-2.0%	-6.9%	0.3%	0.2%
Old Peachtree Road at I-85	PM (3-7 PM)	2.7%	6.9%	5.5%	-3.4%	4.8%	4.5%

Table 12. Net Changes at the Test Sites

Test Site	Peak Hours	Throughput	CO	NO_x	VOC	PM_{10}	$PM_{2.5}$
Shallow Ford Road at I-85 NB	PM (3-7 PM)	2.7%	-0.3%	-4.2%	-8.8%	-2.1%	-2.2%
Moores Mill Road at I-75 SB	AM (6-10 AM)	8.8%	-3.0%	-6.1%	-8.6%	-2.0%	-2.0%
Buford Highway at I-285 WB	AM (6-10 AM)	3.8%	3.5%	-0.3%	-4.8%	1.6%	1.5%
University Avenue at I-75/I-85 SB	PM (3-7 PM)	1.8%	4.5%	-0.9%	-4.0%	4.5%	4.5%
Buford Highway at I-285 EB	AM (6-10 AM)	7.7%	9.7%	3.7%	0.6%	7.5%	7.4%

Table 13. Impacts at the Test Sites

Test Site	Peak Hours	Throughput	CO	NO_x	VOC	PM_{10}	$PM_{2.5}$
Chastain Road at I-575 Paired with Moores Mill Road at I-75 SB	AM (6-10 AM)	37.6%	24.4%	25.8%	2.9%	10.5%	10.0%
Chastain Road at I-575 Paired with Buford Highway at I-285 WB	AM (6-10 AM)	31.2%	29.1%	29.8%	6.2%	13.6%	13.1%
Hickory Grove Road at I-75	AM (6-10 AM)	13.1%	-4.6%	-4.6%	-8.3%	-7.8%	-7.9%
Indian Trail/Lilburn Road at I-85	AM (6-10 AM)	1.7%	-2.6%	-3.4%	-3.2%	-2.5%	-2.5%
Old Peachtree Road at I-85	AM (6-10 AM)	-0.5%	1.5%	-2.5%	-2.0%	-2.1%	-2.1%
Chastain Road at I-575	PM (3-7 PM)	36.6%	20.5%	22.3%	3.9%	9.6%	9.2%
Hickory Grove Road at I-75	PM (3-7 PM)	3.8%	-8.0%	-7.0%	-6.2%	-10.2%	-10.2%
Indian Trail/Lilburn Road at I-85	PM (3-7 PM)	6.2%	2.6%	2.1%	1.8%	2.3%	2.3%
Old Peachtree Road at I-85	PM (3-7 PM)	6.8%	7.2%	9.3%	4.9%	6.7%	6.5%